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***Airfield Pavement Design
For Frost Conditions
& Subsurface Drainage***

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SECTION 1. INTRODUCTION

1. SCOPE. This manual presents criteria for the design of subsurface drainage systems and frost protection for airfield pavements. Included in this manual are criteria for subsurface exploration as it relates to frost and drainage, frost protection, design alternatives for subsurface drainage, and suggested details for subsurface drainage design.

2. CANCELLATION. This manual, *Airfield Pavement Design for Frost Conditions and Subsurface Drainage*,” NAVFAC DM-21.06, cancels and supersedes NAVFAC DM-21.06 of April 1986.

3. RELATED CRITERIA.

Subject	Source
Hydrology	NAVFAC DM-5.02
Drainage Systems	NAVFAC DM-5.03
Pavements	NAVFAC DM-5.04
Soil Mechanics	NAVFAC DM-7.01
Foundations and Earth Structures	NAVFAC DM-7.02
Flexible Pavement Design for Airfields	NAVFAC DM-21.03
Airfield and Heliport Planning and Design	Mil Handbook 1021

4. DEFINITIONS. See appendix A, *Glossary*, for definitions of the key terms used in this manual.

a. Frost. Within the context of this document, frost is the condition of free water freezing within the pavement structure or in the subgrade. The action of frost includes expansion or heaving, as well as the loss of support during the melt period. The frost action may result in the formation of ice crystals in any frost-susceptible material within or below the pavement structure to which freezing temperatures penetrate.

b. Subsurface Drainage. Subsurface drainage refers to the collection and removal of water from a pavement structure or subgrade. Subsurface drainage systems are categorized into two functional categories: one for draining surface infiltration water and the other for controlling groundwater.

c. Pavement Structure . Pavement structure is the combination of subbase, base, and surface layers constructed on a subgrade.

5. SOURCES OF WATER. Free water in a pavement structure and subgrade can come from many different sources, as illustrated in figure 1. Water may seep upward from the groundwater table through capillary suction or vapor movements, or it may flow in laterally from high grounds and shoulder ditches. Surface infiltration through joints and cracks is another major source of water, especially in older deteriorated pavements. On rigid pavements, 25 to 67 percent of rainfall may infiltrate the pavement structure through joints and cracks, depending on pavement condition. On flexible pavements, water can infiltrate through surface cracks, longitudinal cold joints that crack, and pavement edges. Depending on

pavement condition, 25 to 50 percent of rainfall can enter flexible pavements through surface infiltration. Pavement subsurface drainage systems are designed primarily to handle surface infiltration water, but in cut areas or areas with high groundwater, drainage of groundwater can also be an important design consideration.

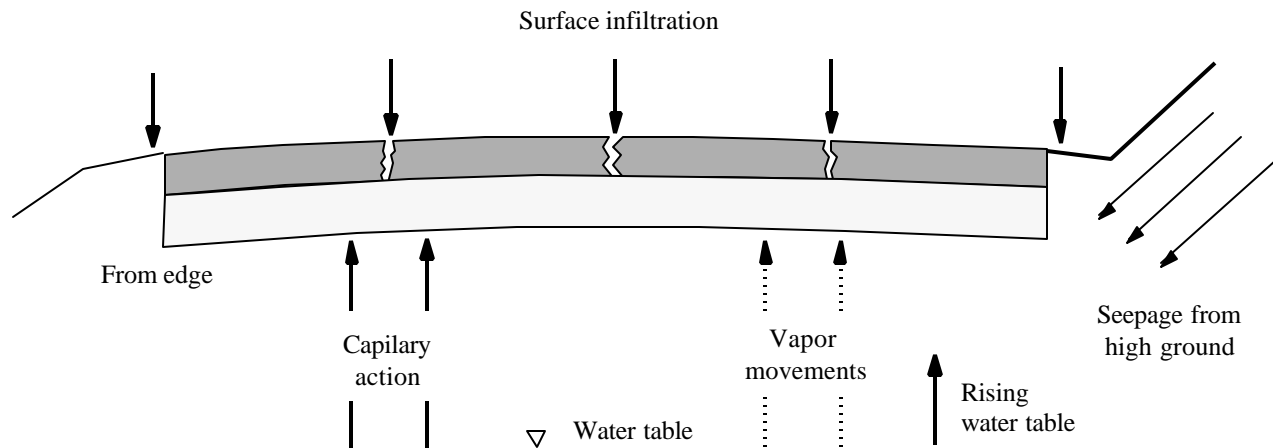
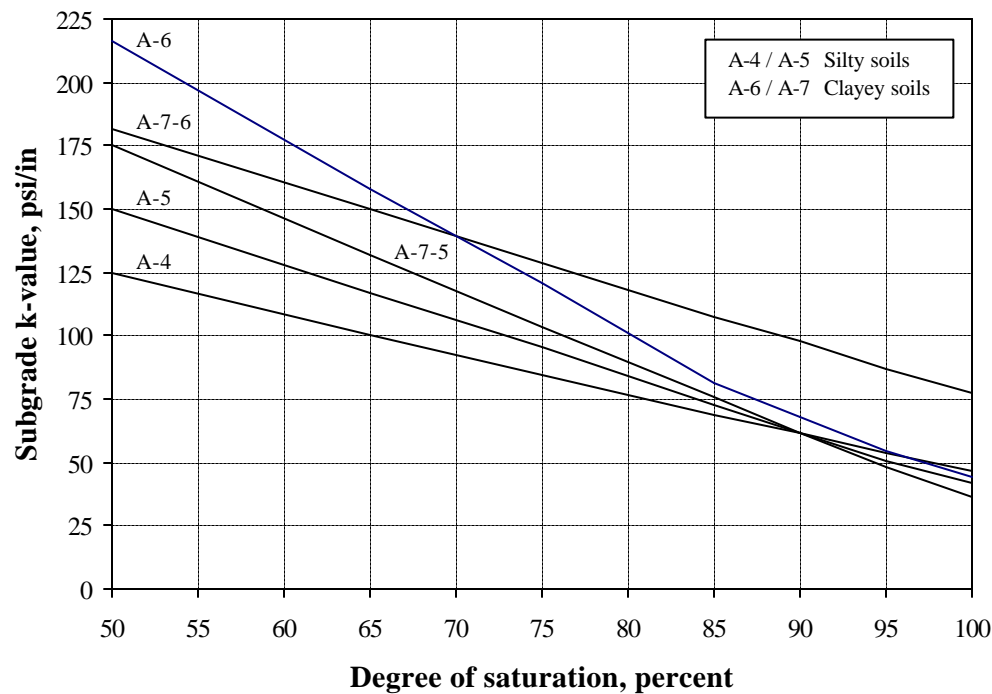


Figure 1. Source of water in pavement structures.

6. EFFECTS OF SUBSURFACE WATER. Many pavement distresses are either caused by water or greatly aggravated in the presence of excess free water. For flexible pavements, softening of the base, subbase, or subgrade upon saturation is one of the main causes of pavement failures. The stiffness of silty and clayey soils can drop by a factor of two or more upon saturation (see figure 2). Such a drop in subgrade stiffness is accompanied by a corresponding increase in pavement deflection. The increased pavement deflections lead to accelerated deterioration of cracks and other distresses. The deflection and performance of rigid pavements are similarly affected by the subgrade softening. For rigid pavements, pumping and loss of support under joints and cracks can also be a significant problem. Under saturated conditions, moving wheel loads can cause movement of free water under very high pressure within the pavement layers. This movement of water can cause erosion of the base and subgrade materials, as well as deterioration of the interface between pavement layers. The increased deflections and the presence of excess free water during saturated conditions can also cause pumping of the subgrade fines into the base layers, resulting in significant loss of stability. In frost areas, excess free water can aid frost activity if susceptible material is present, aggravating the frost-heave problem. Poor subsurface drainage can also aggravate material problems such as D-cracking and reactive aggregate problems in rigid pavements and stripping in flexible pavements.

7. EFFECTS OF FROST ACTION. Frost action can cause differential heaving, cracking, surface roughness, blocked drainage, and a reduction in bearing capacity during thaw periods. The extent of these problems ranges from slight to severe, depending on the type and uniformity of the subgrade soil and availability of water. The most effective method of addressing the effects of frost action is taking measures to avoid this problem. This is typically accomplished by either removing and replacing all frost-susceptible material within frost penetration depth, or providing sufficient cover over the susceptible material with non-frost susceptible material.



1 psi/in = 0.271 MPa/m

Figure 2. Effects of moisture level on stiffness of silty and clayey soils (Hall et al. 1996).

a. Frost Heaving. Upon freezing, the volume of water expands by about 9 percent; however, this volume expansion alone is not sufficient to account for the heaving of several inches or more that occurs in some pavements. Frost heaving results from the growth of ice lenses in susceptible subgrade or unbound materials in the pavement structure. Uniform heave is generally not troublesome, but nonuniform heave can result in serious surface irregularities in flexible pavements and cracking in rigid pavements. Differential heave is usually the result of variations in subgrade soils, soil moisture, and transitions from cut to fill with high groundwater level.

b. Formation of Ice Lenses. Ice lenses form in soils that are highly susceptible to capillary action. As the soil is slowly cooled, the water in the voids begins to freeze to form ice crystals. If the soil is susceptible to capillary action, water is drawn to these ice crystals, which grow to form ice lenses. The ice lenses continue to grow as long as the freezing conditions remain and the supply of water is present. To have serious formation of ice lenses, three conditions must exist:

- Presence of frost-susceptible materials.
- Penetration of freezing temperatures into the susceptible material.
- Available supply of water.

The potential for significant frost heaving is the greatest when the groundwater table is relatively close to the surface and just below the freezing zone. Surface infiltration and lateral flow are other potential sources of water; however, when freezing starts and a layer of ice develops, the water supply from above will be cut off by the ice layer itself.

c. Thawing and Reduction in Bearing Capacity. During thawing periods, the upper ice lenses melt, releasing water into the base course (see figure 3). If the pavement structure is inadequately drained, or if the drains are blocked with ice, the base course becomes saturated and weakened. Traffic during this period causes large pavement deflections and the development of high pore pressures. The resulting problems are the same as those associated with excess free water in the pavement structure discussed under paragraph 6.

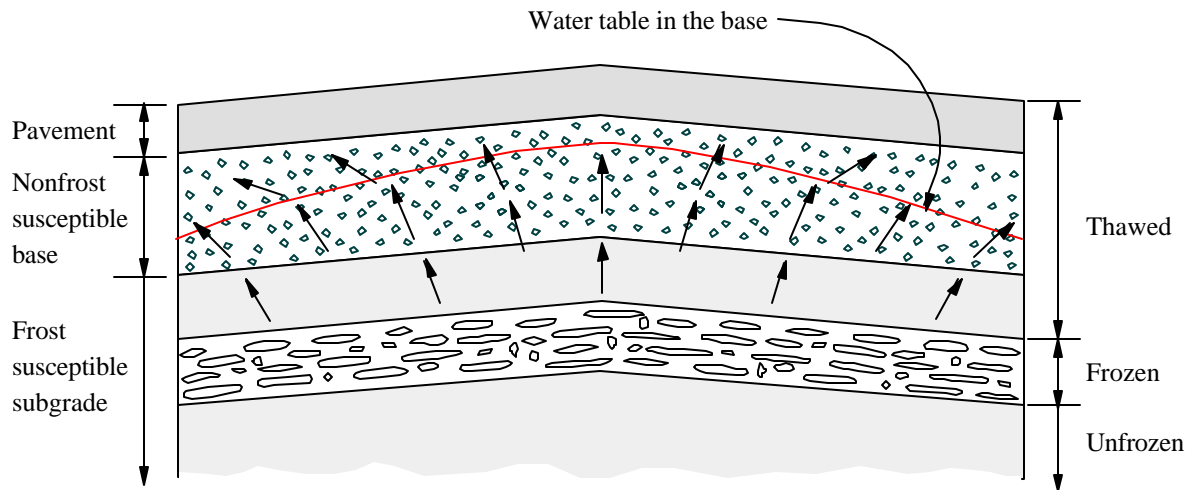


Figure 3. Upward movement of moisture into base course during thaw period.

8. BENEFITS OF SUBSURFACE DRAINAGE. If properly designed, installed, and maintained, subsurface drainage systems can be highly effective in providing longer pavement service life. Moisture-related problems such as pumping, frost heaving, and material problems can drastically reduce the service life of pavements. The effects of poor drainage are particularly detrimental on pavements that have developed distresses. Cracks and deteriorated joints provide entry points for water into the pavement structure, and loads placed over cracks cause substantially higher deflections. The combination of the excess free water and increased pavement deflections leads to accelerated deterioration of cracks under wet conditions. A properly functioning drainage system can prevent or greatly reduce exposure to adverse moisture conditions, thereby improving pavement performance. Good subsurface drainage is important for both flexible and rigid pavements.

SECTION 2. PRELIMINARY DESIGN DATA

1. GENERAL. The need for subsurface drainage and frost protection must be identified during the design stage to enable incorporation of appropriate features into the pavement design. Verification of design assumptions is important to obtain reliable designs. If during construction any of the site conditions were found different than those assumed in the design, the design may have to be modified. Various site-related factors affect the need for frost protection and the need for subsurface drainage. In this section, investigation of those site factors is discussed.

2. INVESTIGATION FOR FROST DESIGN. The key factors that determine the need for frost protection include type and gradation of subgrade, climate, and depth of groundwater table. Frost heaving will occur only if the following three conditions exist:

- Presence of frost-susceptible material.
- Penetration of freezing temperatures into the susceptible material.
- Available supply of water.

The investigation for frost design involves evaluating site conditions for the determination of the presence of these conditions.

a. Subsoil Investigations. Frost action is detrimental if it results in differential heaving, which is caused by variations in subsurface conditions. Variability of subsurface conditions, therefore, is an important consideration for frost design. Subsoil investigation should include assessment of horizontal and vertical variations in subgrade soil type, natural moisture content, and water table elevations. In some situations, variable pavement sections may be needed for different parts of the project to accommodate the differences in subsurface conditions along the project. These conditions must be identified during the subsoil investigation. Consider removing isolated pockets or sections of frost-susceptible soil to eliminate abrupt changes in subgrade conditions.

b. Classification of Soils for Frost Susceptibility. Frost susceptibility of a soil is the potential for the formation of ice lenses in the soil under freezing conditions. Because the water needed for formation and growth of ice lenses is supplied through capillary action, severe frost heave occurs in soils with a high capillarity rate. As the freezing temperatures penetrate deeper into the ground, a heavy formation of ice lenses takes place at each successive level, resulting in severe frost heave. All inorganic soils that contain more than 3 percent by weight of particles finer than 0.02 mm in diameter are generally frost-susceptible. Some uniform sandy soils that contain as much as 10 percent finer than 0.02 mm may remain non-susceptible. These sands are usually interbedded with other soils and, in general, cannot be considered separately. Frost-susceptible soils have been classified into four groups (F1, F2, F3, and F4) according to the degree of susceptibility, as shown in table 1. The following are additional comments on the frost susceptibility of various types of soils:

(1) Sands and Gravels. Little or no frost action is likely to occur under normal freezing conditions in sands, gravels, crushed rock, cinders, and similar granular materials when they are clean and free draining. The large voids permit water to freeze in place without segregation into ice lenses.

(2) Silts. Typical silts, such as rock flour, are highly frost-susceptible because of the combination of relatively small voids, high capillarity, and relatively good permeability of these soils.

(3) **Clays.** Clays are usually cohesive and have high potential capillarity, but their capillarity rate is low. Frost heaving may occur in clays, but not as severely as in silts because of the impervious nature of the clays, which makes passage of water slow. Although significant heaving does not occur in clays, clayey soils are not necessarily free of the adverse effects of frost action. Moisture introduced into the soil during thaw periods because of melting ice can cause a drastic reduction in stiffness of clayey soils. Thawing usually takes place from the top-down, leaving very high moisture content in the upper strata. Upon saturation, the stiffness of clayey soils can drop by a factor of two or more, compared to that under dry conditions.

(4) **Varved Clays.** Varved clays consist of alternating layers of medium gray inorganic silt and darker silty clay. The thickness of the layers rarely exceeds 0.5 in (13 mm). Where subgrade conditions are uniform and there is local evidence that the degree of heave is not exceptional, the varved clay may be assigned to Group F3 for frost susceptibility. Nonuniform varved clays are considered to have very high frost susceptibility.

Table 1. Frost susceptibility classification of soils.

Frost group	Degree of frost susceptibility	Type of soil	Percent finer than 0.02 mm by weight	Typical Soil Classification*
F1	Negligible to low	Gravelly soils	3 to 10	GW, GP, GW-GM GP-GM
F2	Low to Medium	Gravelly soils	10 to 20	GM, GW-GM GP-GM
		Sands	3 to 15	SW, SP, SM, SW-SM SP-SM
F3	High	Gravelly soils	Greater than 20	GM, GC
		Sands, except very fine silty sands	Greater than 15	SM, SC
		Clays, PI > 12 Varved clays existing with uniform subgrade		CL, CH
F4	Very high	All silts		ML, MH
		Very fine, silty sands	Greater than 15	SM, SC
		Clays, PI < 12		CL, CL-ML
		Nonuniform varved clays and other fine grained, banded sediments		CL, ML, SM, CH

*Unified Soil Classification System

c. Temperature Design Values. For frost considerations, the design freezing index is the basic value for measuring temperature effects. Freezing index is proportional to the magnitude and duration of subfreezing temperatures during the winter season. For airfield pavement design, the design freezing index is the freezing index for the coldest year in a 10-year cycle or the average of the three coldest winters in the latest 30 years on record. Figure 4 shows design freezing index values for the continental

United States. Values for locations not shown in figure 4 should be determined using the following terms and the procedure illustrated in figure 5.

(1) Average Daily Temperature. The average of the maximum and minimum temperatures for one day, or the average of several temperature readings taken at equal time intervals (typically on an hourly basis) during one day.

(2) Mean Daily Temperature. The average of the average daily temperatures for a given day for several years.

(3) Degree-Days. The degree-days for any one day is the difference between the average daily air temperature and 32 °F (0 °C). The degree days are negative when the average daily temperature is below 32 °F (freezing degree-days) and positive when it is above 32 °F (thawing degree-days). Figure 5 shows curves obtained by plotting cumulative degree-days against time.

(4) Freezing Index. The number of degree-days between the highest and lowest points on a cumulative degree-days versus time curve (e.g., figure 5) for one freezing season. Freezing index is a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 4.5 ft (1.35 m) above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately below the surface is known as the surface freezing index.

(5) Design Freezing Index. The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the index for the coldest year in the latest 10-year period may be used. The design freezing index at a site with continuing construction need not be changed more often than once in 5 years unless recent temperature records indicate a significant change in thickness design requirements for frost. Design freezing index is illustrated in figure 5.

(6) Mean Freezing Index. The freezing index determined based on mean temperatures. The period over which temperatures are averaged is usually at least 10 years (a period of 30 years is preferred). The latest available data should be used. Mean freezing index is illustrated in figure 5.

d. Local Frost Data. Local history of frost heaving may be a strong indication that careful evaluation of site conditions for frost activities is needed. Study all locally available records of maximum and differential frost heaving of airfield and highway pavement in the area. Local public utility companies may be a good source of information for depth of soil freezing.

e. Water Source for Ice Formation. A groundwater level within 5 ft (1.5 m) of the proposed subgrade elevation is an indication that sufficient water is available for ice lens formation, if the subgrade is frost-susceptible. Other conditions that warrant special attention include the following:

- Homogeneous clay subgrade soils contain sufficient moisture for ice formation, even with the depth to ground water in excess of 10 ft (3.0 m).
- Unsealed joints and cracks in pavement surface, poorly drained pavements, and shoulder surfaces are common sources of trapped water.

Identification of all potential sources of water for frost activity is an important aspect of site investigations. The pavement design should incorporate appropriate joint details and grades to minimize surface infiltration water.

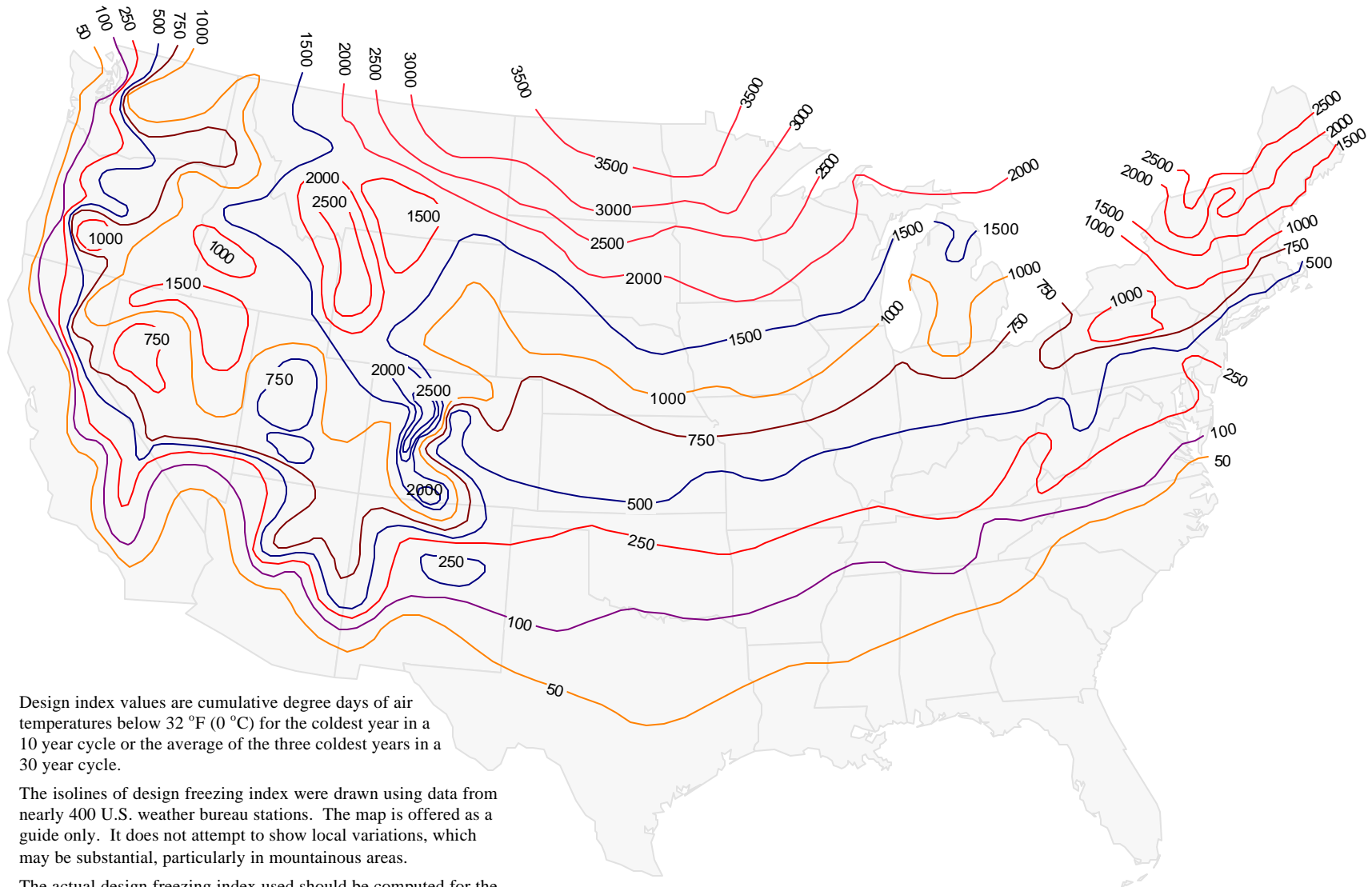
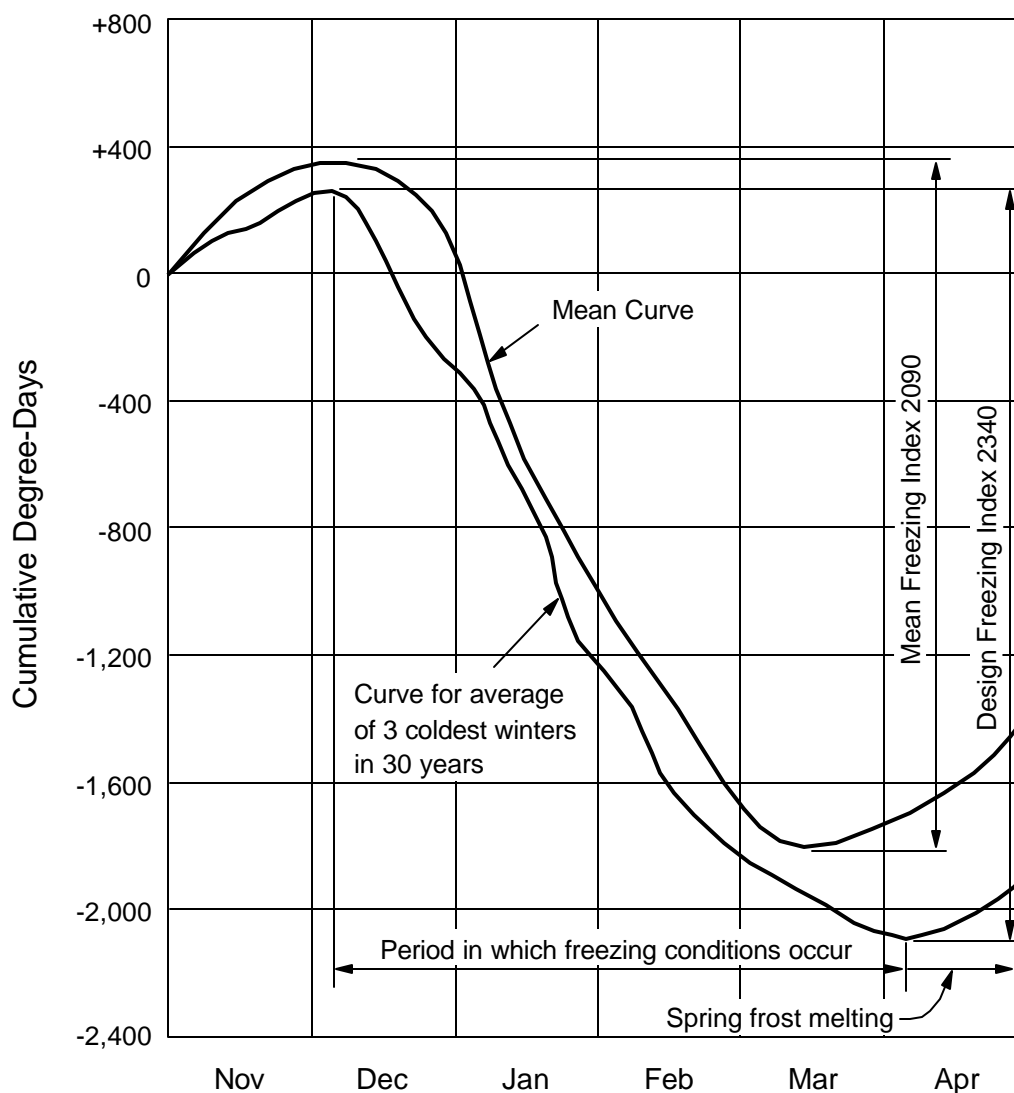


Figure 4. Distribution of design freezing index values in the continental United States.



1 degree-day F = 0.556 degree-days C

Figure 5. Example determination of freezing index.

3. INVESTIGATION FOR SUBSURFACE DRAINAGE DESIGN. The analysis and design of subsurface drainage requires information on prevailing subsurface conditions, as well as information on local climatic conditions. Fundamental material properties are an important aid to classifying materials and determining their ability to transmit water. The climatic factors are an important consideration in identifying the need for subsurface drainage. The information needed for subsurface drainage design includes surface geometry, subsurface geometry, and material properties.

a. Airfield Surface Geometry. The subsurface investigations should begin with an examination of the planned profiles and cross-sections. Information on the planned grades relative to original ground level is needed. The topographical map of the area should also be examined to establish the boundaries of the flow domain.

b. Subsurface Geometry. An accurate assessment of the prevailing subsurface conditions is very important for drainage analysis and design. The information needed includes subsurface soil and rock profiles, natural drainage characteristics, and prevailing groundwater conditions. In general, a thorough program of subsurface exploration and geologic evaluation is needed to obtain this information. A good subsurface exploration is an essential part of airfield pavement design for various purposes. The work needed for the drainage considerations should be incorporated in the overall subsurface exploration program for the project. In many parts of the nation, agricultural or geological maps are available that are very useful in planning the subsurface exploration.

(1) Site Visits. Valuable information pertaining to the existing subsurface drainage conditions can be obtained by careful examination of the site in the field, especially if the visits were made during or immediately following a wet period. It may be possible to observe wet-weather springs or other evidence of intermittent seepage that might not show up during drier periods. The type and condition of the vegetation in the area can also offer some clues on the soil and groundwater conditions. Lush green foliage and the presence of certain types of plants and trees that require a high water table (such as cattails and willows) may be significant indications of potential groundwater problems.

(2) Exploration. Subsurface exploration should be conducted using the techniques described in Mil Handbook 1021 and NAVFAC DM-7.01. During explorations, field crews should obtain all possible data that might relate to subsurface drainage in any way. Any evidence of artesian pressures or loss of wash water during drilling should be noted, and any unusual stratification (e.g., granular layers or lenses within a more cohesive stratum) should be recorded. The sampling should be coordinated so that representative samples are obtained for laboratory testing from all strata that may be involved in the seepage phenomenon. This includes cut materials that will later be placed in fills. When significant seasonal fluctuations in the water table are either known or suspected, installation of groundwater observation wells is highly recommended. Plastic tubing placed in bore holes can be used to monitor changes in groundwater levels over time. Such installations are inexpensive and can provide valuable information.

c. Material Properties

(1) Index Properties. The index properties of materials are those properties that help to identify and classify the material. Index properties can also be an important indicator of material performance. The pertinent index properties for the analysis and design of subsurface drainage are those that influence seepage. The properties in this category include the following:

- Grain size characteristics: ASTM C117, *Testing Methods for Materials Finer than 75 mm (No. 200) Sieve in Mineral Aggregates by Washing*.
- Atterberg Limits:
 - ASTM D 423, *Test Methods for Liquid Limit of Soils*
 - ASTM D 424, *Test Methods for Plastic Limit and Plasticity Index of Soils*

Together, these test results lead to the soil classifications. See NAVFAC DM-7.01 for additional information on soil testing and soil properties.

(2) Engineering Properties. Two properties in this category are important for subsurface drainage considerations: coefficient of permeability and frost susceptibility. The frost susceptibility of materials is discussed earlier in this section, under paragraph 2. Ideally, the coefficient of permeability should be determined by in-situ measurements; however, laboratory determinations are more common

(ASTM D 2434, *Test Methods for Permeability of Granular Soils*). Although field- or laboratory-measured coefficient of permeability is desirable, in practice it is often necessary to use empirically estimated values. Table 2 lists the ranges of values of coefficient of permeability as related to the Unified Soil Classification System. For typical values of coefficients of permeability of compacted soils, see NAVFAC DM-7.02.

Table 2. Approximate correlation between permeability and Unified Soil Classification (FHWA 1980).

Unified Soil Classification	Relative permeability	Coefficient of permeability, k*	
		ft/day	m/day
GW	Pervious	2.7 to 274	0.82 to 84
GP	Pervious to very pervious	13.7 to 27,400	4.2 to 8,350
GM	Semipervious	2.7×10^{-4} to 27	8.2×10^{-5} to 8.2
GC	Impervious	2.7×10^{-5} to 2.7×10^{-2}	8.2×10^{-6} to 8.2×10^{-3}
SW	Pervious	1.4 to 137	0.43 to 41.8
SP	Semipervious to pervious	0.14 to 1.4	0.043 to 0.43
SM	Impervious to semipervious	2.7×10^{-4} to 1.4	8.2×10^{-5} to 0.43
SC	Impervious	2.7×10^{-5} to 0.14	8.2×10^{-6} to 0.043
ML	Impervious	2.7×10^{-5} to 0.14	8.2×10^{-6} to 0.043
CL	Impervious	2.7×10^{-5} to 2.7×10^{-3}	8.2×10^{-6} to 8.2×10^{-4}
OL	Impervious	2.7×10^{-5} to 2.7×10^{-2}	8.2×10^{-6} to 8.2×10^{-3}
MH	Very impervious	2.7×10^{-6} to 2.7×10^{-4}	8.2×10^{-7} to 8.2×10^{-5}
CH	Very impervious	2.7×10^{-7} to 2.7×10^{-5}	8.2×10^{-8} to 8.2×10^{-6}

*When placed as well-constructed rolled-earth embankment with moisture-density control.

d. Climatic Conditions . The climatic information of interest to subsurface drainage analysis and design include annual precipitation and freezing index. In general, precise information on frequency, intensity, and duration of precipitation in an area is not needed. The recommended procedure for hydraulic design does not require any of these factors as an input; however, climatic condition is an important factor for consideration in determining the need for drainage. The climatic zones established under the FHWA *Long-Term Pavement Performance* (LTPP) program are a good indicator of the relative need for drainage. In the LTPP program, the continental United States is divided into four climatic regions based on annual precipitation and freezing index, as shown in figure 6. The wet climate is defined as areas receiving more than 20 in (508 mm) of rainfall per year, and the freeze climate is defined as areas with a design freezing index greater than 150 degree-days F (83.3 degree-days C). In general, good subsurface drainage is most critical for the wet-freeze region and the least critical for the dry-nonfreeze region. Good drainage is also important in all areas where subgrade freezing can occur.

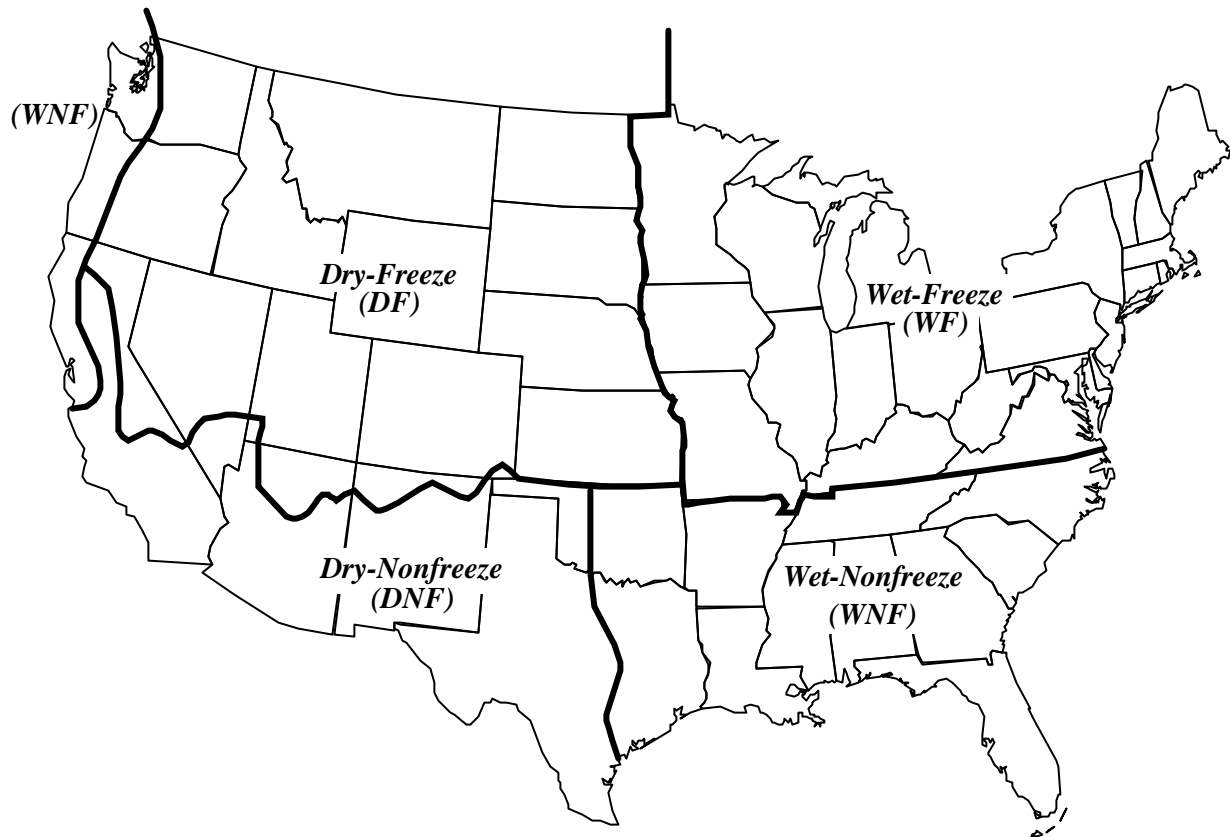


Figure 6. The climatic zones as defined in the FHWA Long-Term Pavement Performance (LTPP) program.

SECTION 3. FROST PROTECTION DESIGN

1. NEED FOR FROST PROTECTION. Differential frost heaving can cause pavement cracking, significant roughness, and a drastic reduction in pavement service life. If prevented from free movement, frost heaving can exert enormous forces on pavements, structures, or utilities. The forces involved are so great that any attempt to accommodate frost heaving by providing a more substantial pavement structure is not practical. The only practical solution is prevention. Even if frost action does not result in significant heaving, the excess free water during thaw periods, and consequent softening of the subgrade and base material, can also be detrimental to pavement performance. If the investigation for frost design (see section 2) reveals that frost action is possible at the project site, frost protection design must be considered. In general, the following combination of conditions denotes a potential for frost action and the need for frost protection:

- Presence of frost-susceptible soil.
- Groundwater level within 5 ft (1.5 m) of the proposed subgrade elevation.
- Frost penetration depth greater than the planned overall thickness of the pavement structure (typically, design freezing index greater than 150 °F [83.3 °C]).

2. DESIGN APPROACH. There are two basic approaches to frost protection: (a) complete prevention of subgrade freezing and (b) limiting frost penetration into the subgrade. The first method involves providing a sufficient cover over the frost-susceptible material to prevent penetration of freezing temperatures into the subgrade. This may require removing and replacing a certain thickness of frost-susceptible material or providing a layer of non-susceptible fill, if the combined thickness of the pavement structure and any fills needed for geometric requirements are not sufficient to provide adequate cover. The second approach allows limited frost penetration into the subgrade. The applicability and details of each of these design approaches are discussed in the following.

3. DESIGN TO PREVENT SUBGRADE FREEZING. In this method, the adverse effects of frost action are eliminated by preventing the freezing temperatures from reaching the frost-susceptible subgrade. This is accomplished by providing a cover of sufficient thickness of nonfrost-susceptible material over the susceptible subgrade.

a. Criteria for Application. This is the only acceptable method of frost protection in all areas where freezing of the subgrade beneath the pavement structure is possible, if accompanied by any of the following conditions:

- Subgrade soil and moisture conditions are extremely variable.
- The subgrade soil belongs to the frost group F3 or F4.
- Limited differential heave can present severe operational problems.

b. Design Procedure .

- (1) Determine the design freezing index and depth of frost penetration from figures 4 and 7, respectively. Adjust these values based on local experience, if reliable information is available.

- (2) The frost penetration depth determined in step (1) above is the required overall pavement thickness, which includes asphalt or concrete surface, base, subbase, and any additional nonfrost-susceptible material courses. The additional depth of material required for frost protection must consist of nonfrost-susceptible material. Refer to Mil Handbook 1021 to determine the minimum required base and subbase thicknesses.

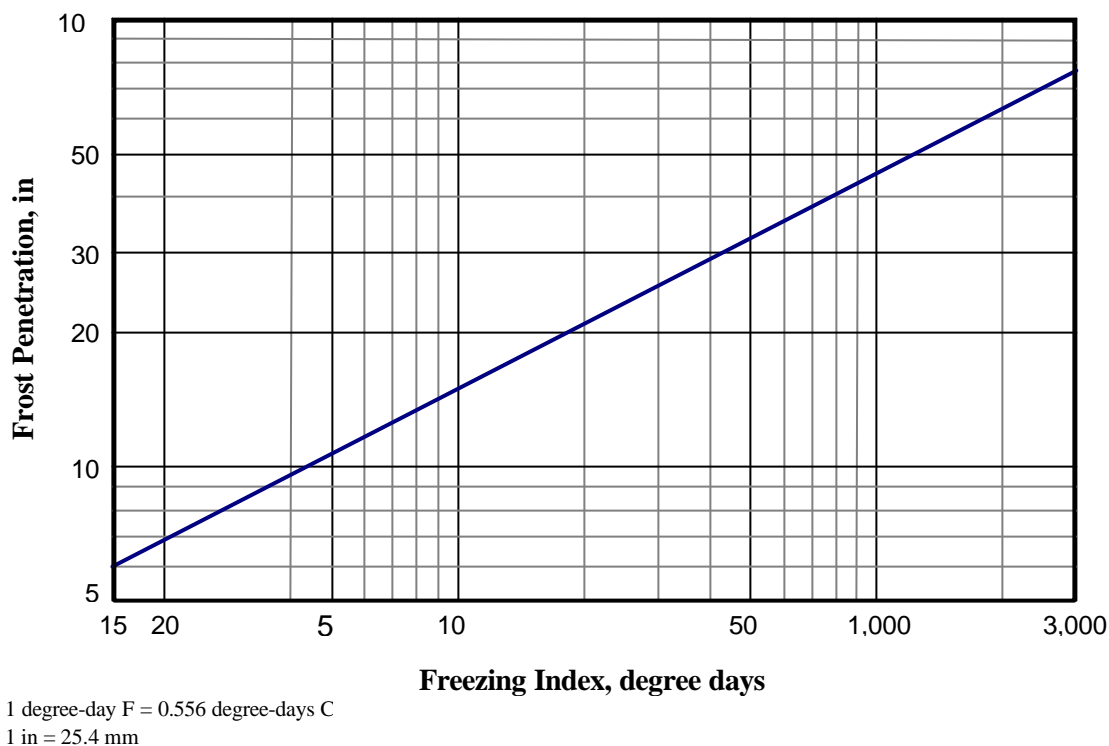


Figure 7. Empirical relationship between freezing index and frost penetration beneath snow-free pavement surfaces (from Corps of Engineers).

4. DESIGN TO LIMIT FROST PENETRATION IN SUBGRADE.

a. Criteria for Application. Use this method for all but the situations described in paragraph 3.a above.

b. Design Procedure .

- (1) Determine the design freezing index and depth of frost penetration from figures 4 and 7, respectively. Adjust these values based on local experience, if reliable information is available.
- (2) From the frost penetration depth determined in step (1) above, subtract the proposed thickness of asphalt or concrete surface course, and multiply the remaining thickness by 2/3. This value is the thickness of limited frost penetration into the subgrade. Provide the required base, subbase, and any additional fill to equal the thickness of limited frost penetration into the subgrade. The material in each of these courses must be nonfrost-susceptible.

5. BASE AND SUBBASE REQUIREMENTS.

a. Nonfrost-Susceptible Materials. Base and subbase courses in areas subjected to frost action must consist of nonfrost-susceptible materials. A conservative general requirement for such materials is that they have less than 3 percent by weight of particles smaller than 0.02 mm. In some cases, laboratory tests may be desirable to determine frost susceptibility of economically available materials that do not meet the general requirements. Currently, a simple and reliable test or criteria for frost susceptibility, which are suitable for general use, are not available. Additional discussion of frost susceptibility of different types of soils is presented in section 2.2.b and table 1. The data in table 1 are based on extensive testing conducted by the U.S. Army Corps of Engineers.

b. Layer Separation. When designing pavements by the limited frost penetration method, a filter/separator layer should be provided between the base (or subbase) and subgrade to prevent infiltration of subgrade fines into the base layers during the thaw periods. A separator layer also prevents mixing of the frost-susceptible subgrade and overlying nonfrost-susceptible materials, thereby minimizing the effects of freezing and preserving the strength of the aggregate base. Either a dense-graded aggregate meeting certain gradation requirements or a geotextile may be used for this purpose.

(1) Aggregate Separator Layer. A dense-graded aggregate base material meeting the following criteria can be used as a separator layer:

$$D_{15 \text{ Filter}} \leq 5 D_{85 \text{ Subgrade}} \quad (1)$$

$$D_{50 \text{ Filter}} \leq 25 D_{50 \text{ Subgrade}} \quad (2)$$

$$D_{15 \text{ Subbase}} \leq 5 D_{85 \text{ Filter}} \quad (3)$$

$$D_{50 \text{ Subbase}} \leq 25 D_{50 \text{ Filter}} \quad (4)$$

The D_x in the above equations is the particle size at which x percent of the particles are smaller than that size. For example, if 15 percent of the particles in the filter material are finer than 0.08 in (2.0 mm), $D_{15} = 0.08$ in (2.0 mm) for the filter material. The following additional requirements are specified to avoid excessive fines in the filter/seperator layer and to obtain a well-graded material:

- The filter material should contain less than 12 percent fines passing the No. 200 sieve (0.075 mm).
- The filter material should have a coefficient of uniformity (CU), as defined below, greater than 20 (preferably greater than 40):

$$CU = \frac{D_{60}}{D_{10}} \quad (5)$$

These checks are automated in the computer program DRIP, which is a Windows® program for pavement subsurface drainage design developed by the FHWA.

The top 6 in (152 mm) of base or subbase can double as the separator layer, if the material satisfies the gradation requirements. Sand, gravelly sand, and screenings that meet the above requirements for

aggregate separator layer may also be used. The minimum recommended thickness of an aggregate separator layer is 6 in (152 mm). However, on soft subgrade (CBR < 4), 6 in (152 mm) of aggregate separator may not be sufficient to prevent some pumping of subgrade fines into the base. For soft subgrade, the use of a geotextile separator layer is recommended. Alternatively, the subgrade soil may be stabilized to improve subgrade strength (see section 3.5.c).

(2) Geotextile Separator Layer. When readily available aggregate base material does not meet the requirements for separator layer, a synthetic fiber fabric may be used to serve as the separator layer. The use of geotextile separator layer is also recommended if the subgrade at the project site is very soft (CBR < 4). There are two basic types of fabrics: woven and nonwoven. The types of fibers used in geotextiles include polypropylene, polyethylene, polyester, polyamides, nylon, and glass. Numerous tests are available for evaluating geotextiles. The majority of these tests had been developed for measuring properties of fabrics that were originally designed for applications other than reinforcement or separation of soil layers. Those properties that are considered important for the performance of the fabrics over clay soils are shown in table 3, along with a listing of the applicable standard testing procedures. Table 9 (Section 4) provides a listing of representative geotextile fabrics.

Table 3. Specifications for fabrics used in pavement layer separation and filtration (AASHTO-ABC-ARBTA joint committee recommendation)¹.

Fabric Property	Test Method	Fabric Requirements (Minimum Values) ²	
		Class A ³	Class B ⁴
Grab tensile strength	ASTM D4632	180 lb (801 N)	80 lb (356 N)
Elongation	ASTM D4632	n/a	n/a
Seam strength ⁵	ASTM D4632	160 lb (712 N)	70 lb (311 N)
Puncture strength	ASTM D4833	80 lb (356 N)	25 lb (111 N)
Burst strength	ASTM D3787	290 psi (2.0 MPa)	130 psi (0.9 MPa)
Trapezoid tear strength	ASTM D4533	50 lb (222 N)	5 lb (22 N)

1. Acceptance of geotextile material shall be based on ASTM D4759. Contracting agency may require a letter from the supplier certifying that its geotextile meets specification requirements.
2. Minimum requirements for value in weaker principal direction. All numerical values represent minimum average roll value (i.e., test results from any sampled roll in a lot shall be or exceed the minimum specified values in the table). Stated values are for noncritical, nonsevere applications. Lot samples according to ASTM D4354.
3. Applications where very coarse, sharp or angular aggregate is used, a heavy degree of compaction (>95 % AASHTO T99) is specified, or depth of trench is greater than 10 ft (3.0 m).
4. Applications where geotextile is used with smooth graded surfaces having no sharp angular projections, no sharp angular aggregate is used, compaction requirements are light (< 95% AASHTO T99), and trench depth is less than 10 ft (3.0 m).
5. Values apply to both field and manufactured seams.

The properties listed in tables 3 and 9 relate to the survivability and endurance of geotextiles. Geotextiles used in the separator layer application must also satisfy the filter and permeability criteria. A product with the appropriate size pore opening must be used to prevent pumping of fines through the geotextile and to avoid clogging. The geotextile must have permeability several times greater than the subgrade to ensure free drainage of the water out of the subgrade. In general, the permeability requirement is not a

problem because most subgrades have relatively poor permeability. The requirements for the geotextile pore opening are as follows:

$$\text{Woven geotextile:} \quad O_{95} \leq D_{85} \quad (6)$$

$$\text{Nonwoven geotextile:} \quad O_{95} \leq 1.8 D_{85} \quad (7)$$

$$O_{50} \leq 0.5 D_{85} \quad (8)$$

$$O_{95} \leq \text{No. 50 sieve} \quad (9)$$

$$O_{95} \geq 3 D_{15} \quad (10)$$

The O_x is the opening size at which “x” percent of the single-size glass beads pass the geotextile, when tested in accordance with ASTM D 4751, *Determining Apparent Opening Size (AOS) of a Geotextile*. The sieve number that corresponds to O_{95} is also known as the AOS. The criteria (6) through (9) above are the soil retention and filter criteria. Criterion (10) is to prevent clogging. Also for clogging considerations, the percentage of open area for woven fabric must be greater than 4, and the porosity of nonwoven fabric must be greater than 50 percent.

c. Stabilization.

(1) Subgrade Soil. Subgrade soil may be stabilized with lime, fly ash, or portland cement to improve strength or to mitigate frost susceptibility. For soft subgrade ($\text{CBR} < 4$), stabilization or a deep granular fill may be needed to ensure desirable pavement performance. However, soil stabilization must be used with care in frost areas because some soils may become frost-susceptible when stabilized and perform more poorly. Few quantitative data are available on suitability and durability of stabilized materials in seasonal frost areas. Thus, testing of the stabilized material is essential to avoid any frost-related problems.

(2) Base. Reflection cracking is a frequent problem for asphalt concrete surfaces constructed on a cement-treated or lean concrete base. The cause of the problem is shrinkage cracks in these bases. The random cracks in these bases can also reflect through concrete surfaces, but reflection cracking is a less frequent problem on rigid pavements. A similar problem is possible on full-depth asphalt pavements placed directly on stabilized soil without an aggregate base. In seasonal frost areas, random cracking is particularly undesirable because of the increased potential for surface infiltration through the cracks. To avoid random reflection cracking, a cement-treated or lean concrete base should not be used on flexible pavements. On rigid pavements, reflection cracking can be avoided by notching the base at the proposed joint locations and sawing joints on the concrete surface directly above the notches.

6. OVERRUNS AND SHOULDER PAVEMENTS. Overrun, blast protection, and shoulder pavements should be designed for frost action. These pavement areas will normally be designed per NAVFAC DM-21.03. In frost-susceptible areas, the thickness should also comply with the requirements of this manual.

7. PERMAFROST. Permafrost areas do not occur within the continental United States, except Alaska.

SECTION 4. SUBSURFACE DRAINAGE DESIGN

1. NEED FOR SUBSURFACE DRAINAGE. Subsurface drainage systems are needed most often to address the water infiltrating the pavement structure through joints and cracks. The need for this type of drainage system depends on site conditions, including annual precipitation, freezing index, traffic level, and subgrade type. Subsurface drainage may also be needed in seasonal frost areas to minimize the potential for frost damage, as well as damage due to melt water during thaw periods. In some cases, high groundwater or seepage from high grounds may require the installation of a groundwater drainage system to lower the groundwater level beneath the pavement to an acceptable level.

a. Frost Action in the Subgrade. Subsurface drainage is required when subgrade freezing can occur beneath the pavement structure. Subgrade freezing is possible if the frost penetration depth is greater than the total thickness of the proposed pavement structure and any non-susceptible fill that will be placed beneath the pavement structure (see section 3). If the pavement is designed to prevent or limit frost penetration into the subgrade in accordance with section 3, subsurface drainage is not required.

b. Surface Infiltration.

(1) Base Course Drainage. Base course drainage is needed to remove water infiltrating the pavement structure through joints and cracks, unless the subgrade has sufficient permeability to allow vertical drainage. Provide base course drainage for all airfield pavements, except under the following conditions:

- When the natural subgrade has a permeability of at least 1 ft/day (0.3 m/day). Table 2 lists the range of permeability of different types of soils. To allow vertical drainage through subgrade, the unbound base material must also have a minimum permeability of 1 ft/day (0.3 m/day).
- In dry regions (as defined in section 2.3.d), if the aggregate base (or subbase) has a permeability of at least 2 ft/day (0.6 m/day) and is daylighted. In seasonal frost areas, subsurface drainage may still be needed for frost considerations.
- The drainage requirement may be waived for pavements in nonfrost areas designed for light traffic.

Where base course drainage is required, the use of a rapid-draining, permeable base will often be necessary to satisfy the drainage requirements. On airfield pavements (especially runways), the drainage path is typically too long for a dense-graded base to provide sufficient drainage in an acceptable time. If satisfactory drainage cannot be achieved within an acceptable time, the use of a permeable base is necessary. Provide a permeable base for the following conditions:

- When 50 percent drainage of the base layer cannot be achieved within 10 days after the end of a rain event.
- Consider using a permeable base in wet regions (more than 20 in [254 mm] of rain per year; see figure 6) if the airfield will be subjected to heavy traffic volumes.

Use either equation 17 (shown in figure 10) or DRIP to determine the time to 50 percent drainage. For typical design conditions, a base permeability of 20 ft/day (6.1 m/day) or more for runways and 10 ft/day (3.0 m/day) or more for taxiways is required to satisfy the time-to-drain requirement.

(2) Surface Drainage. Good surface drainage is very important to minimize the amount of water infiltrating the pavement structure. It is far easier and faster to remove surface water than the water that has infiltrated the pavement structure. Adequate cross slope must be provided to prevent ponding of water on the pavement surface. The cross slope requirements for drainage considerations are as follows:

(a) *Longitudinal Slope*. The longitudinal slope is a concern only for the removal of water from collector drains. Longitudinal slope is not required for good surface drainage. See section 4.4.a.3 for discussion of the longitudinal slope requirements for collector drains.

(b) *Transverse Slope*. Adequate transverse slope is very important for good surface drainage. Provide the maximum slope allowed by the geometric design manual (Mil Handbook 1021). A minimum transverse slope of 1.5 percent (0.015 ft/ft or m/m) is required. For shoulders and the turf area along the pavement edge, the minimum recommended transverse slope is 3 percent (5 percent preferred) to promote rapid drainage of surface runoff into the drainage ditch.

The surface runoff must be directed into drainage ditches or storm drains to prevent infiltration into the pavement structure. Inlets and storm drains should be provided at low points on the pavement to drain away the water that may otherwise pond at those locations. Maintaining joints and cracks well sealed is also important for minimizing surface infiltration.

c. High Groundwater. Subsurface drainage may be needed to address high groundwater or seepage from high grounds. In general, cut areas are particularly prone to high groundwater problems and, therefore, warrant special attention. Consider the effects of seasonal variation in groundwater levels in determining the need for both subgrade and interceptor drains.

(1) Subgrade Drains. Provide subgrade drainage when the groundwater level will rise to within 1 ft below the bottom of the base course.

(2) Interceptor Drains. Identifying the need for interceptor drains requires careful investigation of local conditions. Where seepage from high grounds can raise the groundwater level to within 1 ft (0.3 m) of the bottom of the base course, provide interceptor drains to cut off seepage and lower the groundwater level beneath the pavement structure (see figure 8).

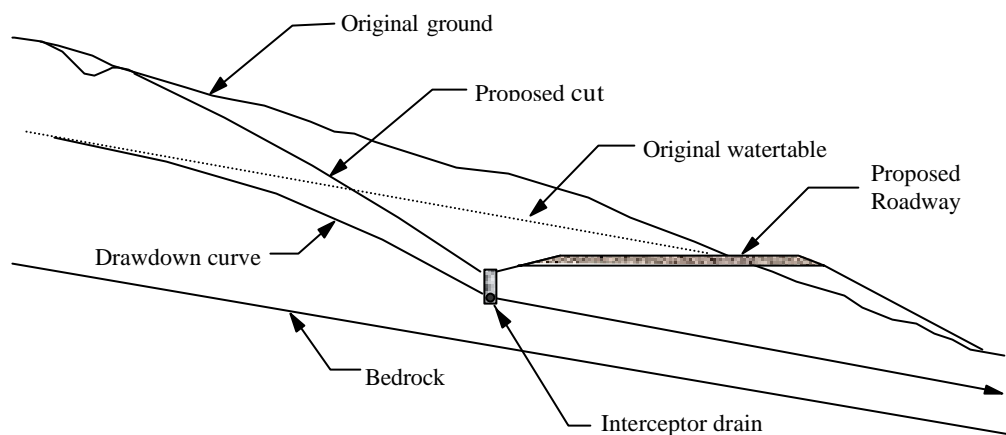


Figure 8. Interceptor drain used to cut off seepage from high grounds and lower groundwater table.

2. HYDRAULIC DESIGN. This section provides the procedure for calculating drainage capacity requirements. Before proceeding with this section, the need for drainage should have already been established per section 4.1. The design equations presented in this section are automated in DRIP.

a. Base Course Drainage. The basic approach to drainage design for the base course in this manual is to minimize its exposure to saturated conditions. This is accomplished by ensuring that a certain level of drainage is achieved within a specified time after the rain has ended.

(1) **Time to Drain.** Use either equation 17 (figure 10) or DRIP to determine the time required to drain the base course for the trial design. The drainage requirements are as follows:

- Dense-graded base: 50 percent drainage in 10 days or less. For typical design conditions, a base permeability of 20 ft/day (6.1 m/day) or more for runways and 10 ft/day (3.0 m/day) or more for taxiways is required to satisfy this requirement.
- Permeable base: 50 percent drainage in 1 day or less. Use 6-in (152-mm) thick treated base when using a permeable base. For typical design conditions, a base material with permeability about 1,000 ft/day (300 m/day) will provide adequate drainage.

Achieving the target level of drainage following a rain event is less time-critical for airfield pavements than highways, because airfield pavements are typically subjected to far less traffic volume. However, adequate drainage must be achieved within a reasonable time to prevent constant high levels of moisture in the pavement structure. The guidelines for quality of drainage are given in table 4.

Table 4. Quality of drainage rating for highways and airfield pavements.

Quality of Drainage	Time to Drain	
	Highways	Airfields
Excellent	2 hr	1 day
Good	1 day	7 days
Fair	7 days	15 days
Poor	30 days	30 days

The time-to-drain calculation requires the following input (automated in DRIP):

- S_R — Resultant slope of the roadway. Most pavements have slope in both transverse and longitudinal directions, as shown in figure 9. If longitudinal slope is less than 0.5 percent S_R may be approximated as S_T .

$$S_R = \sqrt{S_T^2 + S_L^2} \quad (11)$$

where

S_R = Resultant slope, ft/ft (m/m).

S_T = Transverse slope, ft/ft (m/m).

S_L = Longitudinal slope, ft/ft (m/m).

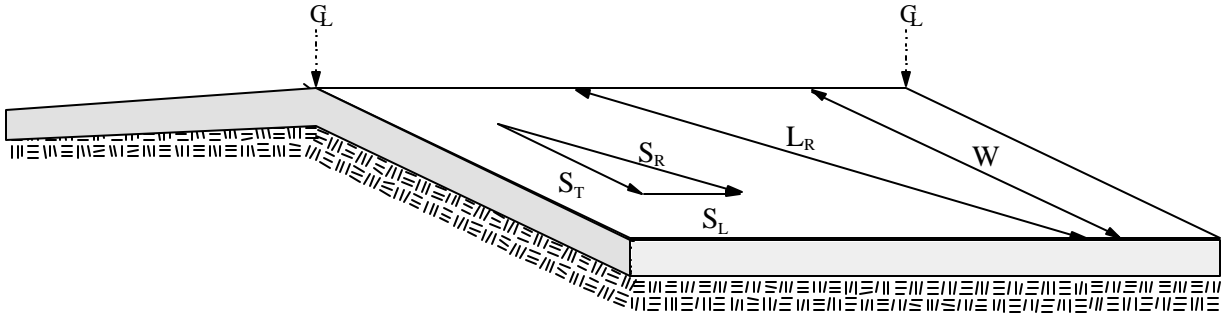


Figure 9. Illustration of resultant slope and drainage path.

- L_R — Resultant drainage path (see figure 9). The drainage path will follow the resultant slope. For longitudinal slope less than 0.5 percent, L_R may be approximated as W .

$$L_R = W \frac{S_R}{S_T} \quad (12)$$

where

L_R = Resultant drainage path, ft (m).

W = Transverse drainage path, ft (m) (see figure 9).

S_R = Resultant slope, ft/ft (m/m).

S_T = Transverse slope, ft/ft (m/m).

- n_e — Effective porosity. Use either equation 13 or 14 to determine n_e . For base materials, equation 14 is recommended.

$$n_e = n - w_e \frac{g_d}{g_w} \quad (13)$$

$$n_e = n WL \quad (14)$$

where

n_e = Effective porosity.

n = Porosity.

$$n = 1 - \frac{g_d}{G_s g_w} \quad (15)$$

g_t = Dry density of the material, pcf.

g_w = Unit weight of water, pcf (62.4 pcf [1.0 Mg/m³]).

G_s = Specific gravity of solids (2.65 to 2.70 for typical aggregate material).

w_e = Effective water content (water content after the specimen has drained to a constant weight), decimal fraction of dry unit weight.

WL = Water loss. The amount of water that can be drained, decimal fraction of total voids (see table 5 for WL values).

Table 5. Typical water loss values for n_c determination (FHWA 1994).

		Type and Amount of Fines								
		Filler			Silt			Clay		
		2.5%	5%	10%	2.5%	5%	10%	2.5%	5%	10%
Material Type	Gravel	70	60	40	60	40	20	40	30	10
	Sand	57	50	35	50	35	15	25	18	8
Notes: Fines are defined as the material passing the No. 200 sieve. For gravel with 0 percent fines, water loss is equal to 80 percent. For sand with 0 percent fines, water loss is equal to 65 percent.										

- k — Coefficient of permeability. Estimate coefficient of permeability of all base material using the guidelines given in NAVFAC DM-7.01. Table 6 shows approximate values of coefficient of permeability of remolded samples of sand and gravel base materials.

(a) Dense Graded Base. If more than one aggregate base layer will be used, determine the average coefficient of permeability using equation 16.

$$k_a = \frac{k_1 d_1 + k_2 d_2 + k_3 d_3 + \dots + k_n d_n}{d_1 + d_2 + d_3 + \dots + d_n} \quad (16)$$

where:

k_a = Average coefficient of permeability of all base layers, ft/day (m/day).

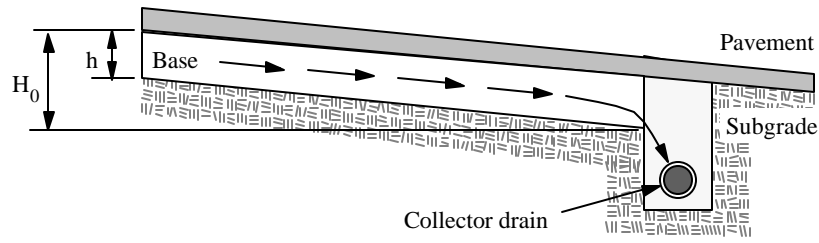
k_1, k_2, k_3, \dots = Coefficient of permeability of individual base layers, ft/day (m/day).

d_1, d_2, d_3, \dots = Thickness of individual base layers, in (mm).

(b) Permeable Base. If a permeable base is used, the permeability of dense-graded base layers can be ignored because the permeability of a permeable base is several orders of magnitude greater than that of a dense-graded base.

Table 6. Approximate values of coefficient of permeability of remolded sand and gravel base material.

Percent by Weight Passing No. 200 Sieve	Coefficient of Permeability, k	
	ft/day	m/day
3	140	43
5	14	4.3
10	1.4	0.43
15	0.14	0.043
25	0.014	0.0043



- Assumptions :
1. Base course is saturated.
 2. No inflow occurs during drainage of base course.
 3. Subgrade is impervious.
 4. Base course has unimpeded flow into the collector drain.

Time for 50 Percent Drainage:

$$t_{50} = \frac{n_e L_R^2}{2.08 k H_0} \quad (17)$$

where:

t_{50} = Time required to drain 50 percent of drainable water from the aggregate base, days.

n_e = Effective porosity (equation 14).

L_R = Resultant drainage path, ft (m) (equation 12).

k = Coefficient of permeability of the base material, ft/day (m/day).

H_0 = Head difference as shown in above figure, ft (m).

$$H_0 = S_R L_R + h \quad (18)$$

S_R = Resultant slope, ft/ft (m/m) (equation 11)

h = Base thickness, ft (m).

Figure 10. Time-to-drain calculation for airfield pavements.

(2) Base Course Discharge. The maximum rate of discharge from the base course is needed in determining the required outlet spacing for the collector drains. Determine the maximum discharge from the base layer using equation 19.

$$q_b = k S_T h \quad (19)$$

where:

q_b = Maximum rate of discharge from base course, ft³/day/ft (m³/day/m).

k = Permeability of the base material, ft/day (m/day).

S_T = Transverse slope, ft/ft (m/m).

h = Base thickness, ft (m).

b. Subgrade Drains. The assumptions for the subgrade drainage and the equation for determining the rate of discharge for the subgrade drains are shown in figure 11.

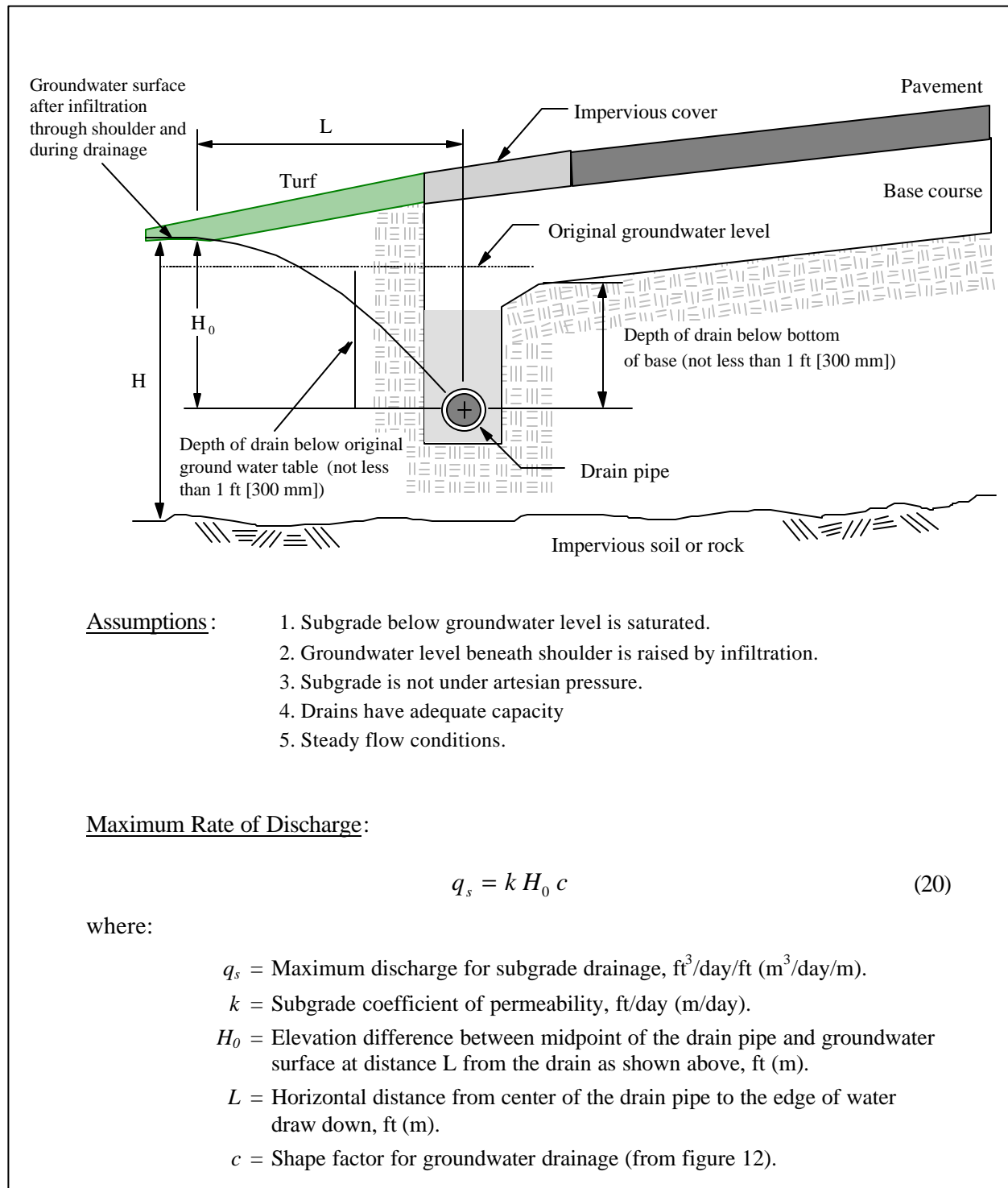
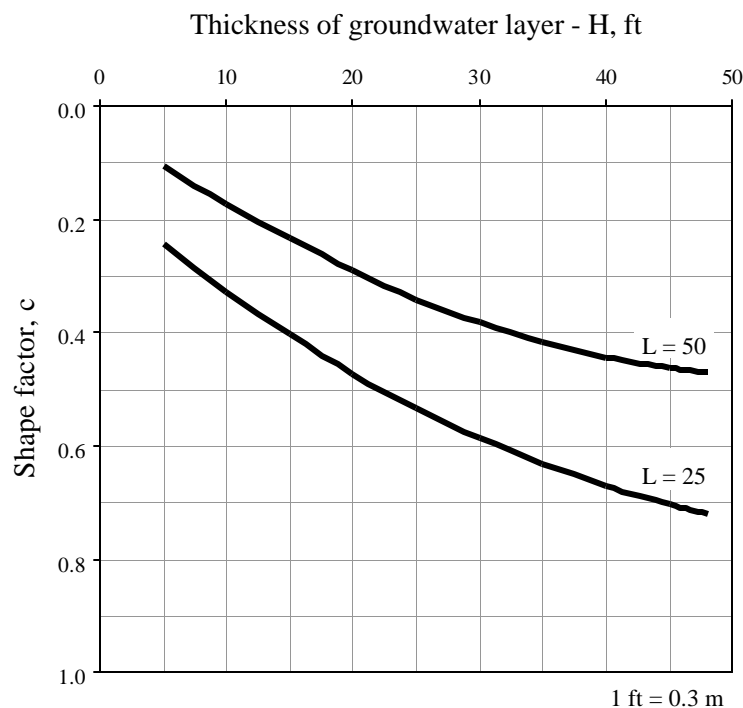


Figure 11. Maximum discharge calculation for subgrade drains.

**Notes:**

H = Thickness of the groundwater layer, as shown in figure 10.

Use L = 50 curve if subgrade permeability is greater than 1.4 ft/day (0.43 m/day).

Use L = 25 curve if subgrade permeability is less than or equal to 1.4 ft/day (0.43 m/day).

Figure 12. Shape factor for subgrade drainage.

(1) Use equation 20 to determine the maximum rate of discharge for subgrade drainage. Modify method of analysis where local information indicates that a more precise analysis is possible. Consider infiltration from the shoulder areas in any modified analyses. Where subgrade drains are being considered, good surface drainage is particularly important to minimize the amount of water that must be removed through a subsurface drainage system.

(2) The subgrade drains may be combined with base course drains. The collector drains for the base course drainage can be designed to handle the water from both sources. For the combined drainage system, if the subgrade permeability is less than 1 ft/day (0.3 m/day), the discharge from the groundwater source is small compared to the base course discharge and may be ignored.

c. Interceptor Drains. Use equation 21 to estimate the discharge from interceptor drains. The parameters used in the calculation are illustrated in figure 13, along with the chart for shape factor.

$$q_i = c' k S H \quad (21)$$

where:

q_i = Maximum discharge from interceptor drain, ft³/day/ft (m³/day/m).

c' = Shape factor for interceptor drain (figure 13).

k = Subgrade coefficient of permeability, ft/day (m/day).

S = Slope of the impervious layer, ft/ft (m/m) (figure 13).

H = Thickness of the groundwater layer, ft (m) (figure 13).

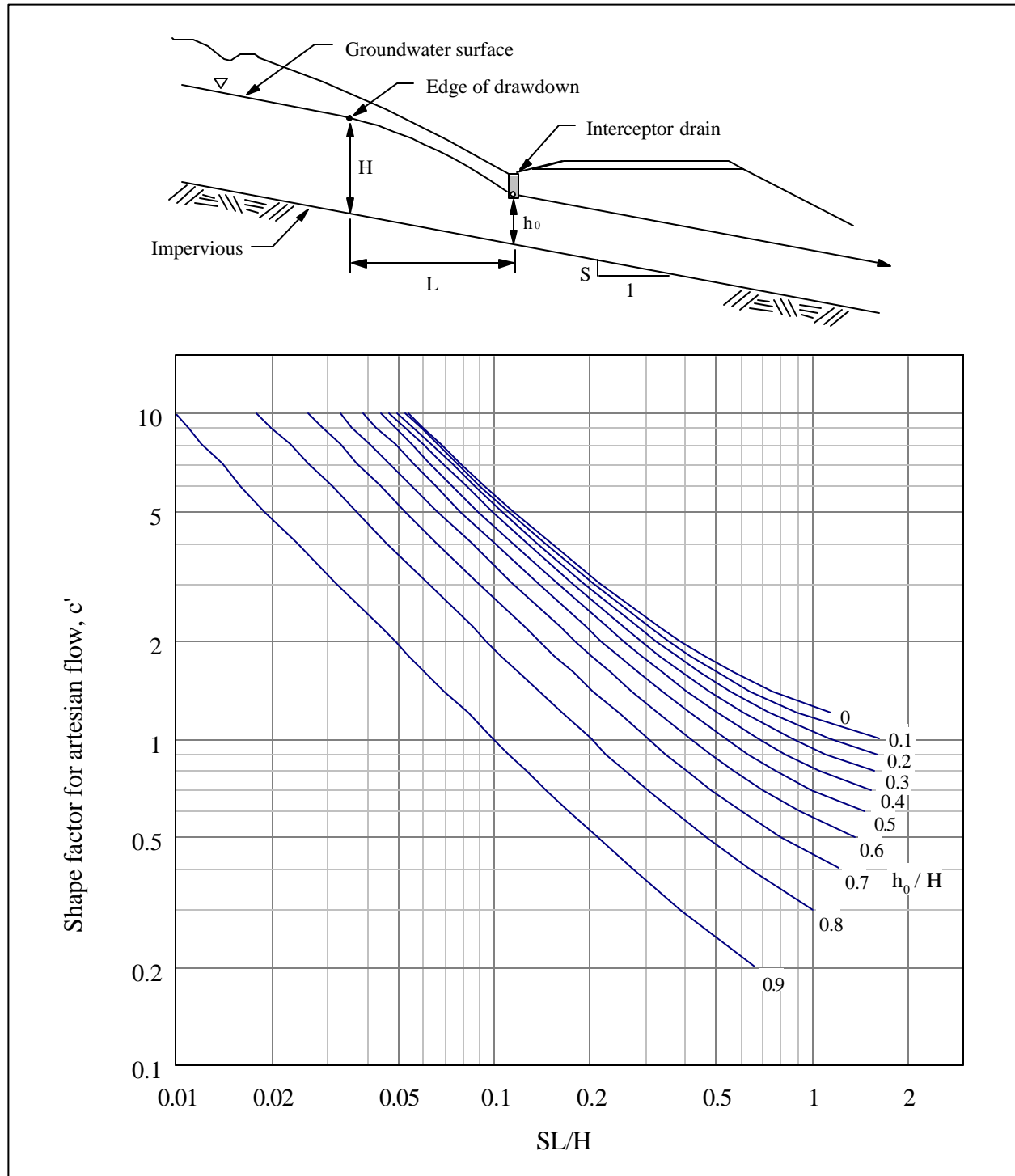


Figure 13. Shape factor for interceptor drain.

(1) The minimum requirement for a subsurface drainage system is to place a 6-in (152-mm) pipe drain with the maximum outlet spacing of 500 ft (150 m). In general, this design will provide ample drainage capacity for interceptor drains.

(2) The interceptor drains may be combined with base course drains. For the combined drainage system, if the subgrade permeability is less than 0.01 ft/day (0.003 m/day), the discharge from the groundwater source is small compared to the base course discharge and may be ignored.

d. Collector Drain Capacity. The collector drain capacity can be estimated using the Manning's equation:

$$Q = \frac{1.486}{n} A \left(\frac{d}{4} \right)^{2/3} S^{1/2} \quad (22)$$

where:

Q = Pipe capacity, ft³/sec

n = Manning's roughness coefficient.

A = Cross sectional area of the drainage pipe, ft².

d = Pipe diameter, ft.

S = Slope of the pipe drain (longitudinal slope), ft/ft.

For circular pipes, equation 21 reduces to the following:

$$Q = \frac{40,000}{n} d^{8/3} S^{1/2} \quad (23)$$

where:

Q = Pipe capacity, ft³/day

n = Manning's roughness coefficient.

$n = 0.012$ for smooth pipe.

$n = 0.024$ for corrugated pipe.

d = Pipe diameter, ft.

S = Slope of the pipe drain (longitudinal slope), ft/ft.

Note the unit conversion incorporated in equation 23, which gives the flow capacity of the pipe in terms of ft³/day. In SI units, equation 23 is as follows:

$$Q = \frac{26,920}{n} d^{8/3} S^{1/2} \quad (24)$$

where:

Q = Pipe capacity, m³/day

n = Manning's roughness coefficient (same values as equation 23).

d = Pipe diameter, m.

S = Slope of the pipe drain (longitudinal slope), m/m.

e. Outlet Spacing. For maintenance considerations, long outlet spacing is not desirable. The shorter outlet spacing is especially important in areas with flat grades. The maximum allowable outlet spacing for collector drains are as follows:

- Smooth pipes: 500 ft (150 m).
- Corrugated pipes: 250 ft (75 m).

In general, the outlet spacing requirements based on maintenance considerations are much more stringent than those based on hydraulic requirements. Nevertheless, hydraulic requirements must be checked to ensure that the subsurface drainage system provides unimpeded flow of infiltrated water out of the pavement structure. The maximum outlet spacing based on the hydraulic requirement is given by equation 25.

$$L = \frac{Q}{q} \quad (25)$$

where:

L = Outlet spacing, ft (m).

Q = Flow capacity of the drain pipe, ft³/day (m³/day).

q = Maximum discharge from all contributing sources of water, ft³/day/ft (m³/day/m)

Include the discharge from all sources that the collector drain is designed to handle:

- Base course drainage only: $q = q_b$ (26)

- Base course and subgrade drainage: $q = q_b + q_s$ (27)

- Base course, subgrade, and intercept drainage: $q = q_b + q_s + q_i$ (28)

where:

q_b = Base course discharge (equation 19).

q_s = Subgrade discharge (equation 20).

q_i = Interceptor drain discharge (equation 21).

For interior drains (figure 17), the collector drain must handle discharge from both sides of the drain. For interior drains,

$$q = 2 q_b \quad (28)$$

The base course discharge (q_b) given by equation 19 is the peak flow from the base layer. The outlet spacing based on equation 19, therefore, is the most conservative value. For most design situations, the conservative outlet spacing based on equation 19 is desirable. However, the outlet spacing based on equation 19 can be overly conservative when a very highly permeable base ($k > 3,000$ ft/day [1,000 m/day]) is used. Where a very highly permeable base is used, the following equation may be used to obtain more realistic estimate of the required outlet spacing:

$$q_b = W h n_e U 24 / t \quad (29)$$

where:

- q_b = Base course discharge from based on time-to-drain, ft³/day/ft (m³/day/m).
 W = Base width (half of the total pavement width for crowned sections), ft (m).
 h = Base thickness, ft (m).
 n_e = Effective porosity of the permeable base (equation 14).
 U = Degree of drainage, fraction.
 t = Time to drain, hours.

According to table 4, 50 percent drainage achieved in 12 hours is excellent drainage for airfield pavements. Substituting these values in equation 29 gives equation 30:

$$q_b = W h n_e \quad (30)$$

3. DESIGN ALTERNATIVES. Three different types of subsurface drains are considered in this manual: base course drains, subgrade drains, and interceptor drains.

a. Base Course Drains. The base course drains consist of collector drains placed along the outer edges of the pavement. The drains may be provided with or without a permeable base, depending on site conditions (see section 4.4 for design details). Figure 14 shows the typical design for the base course drains on pavements with a dense-graded base. The typical design for a permeable base system is shown in figure 15.

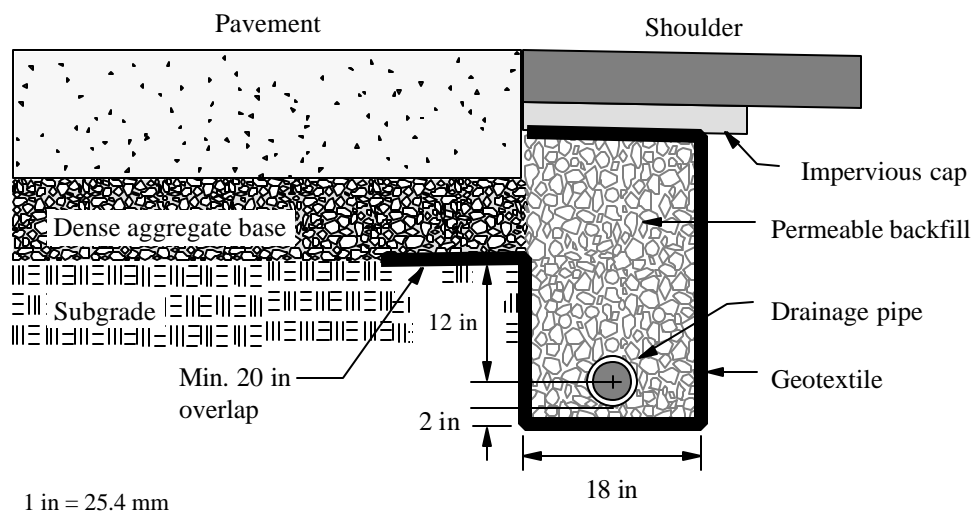


Figure 14. Typical design for base course collector drains for a pavement with a dense-graded base.

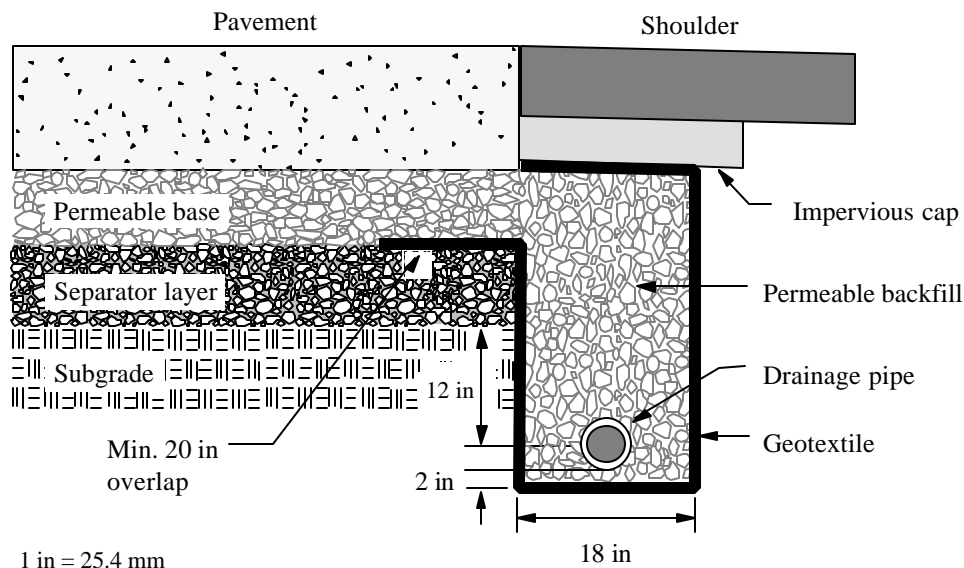


Figure 15. Typical design for base course collector drains for a pavement with a permeable base.

(1) Collector Drains. The design of the collector drain is the same for both systems, with a minor difference in the placement of geotextile. The key design features of the collector drains include the following :

- Perforated drainage pipe placed a drainage trench (see section 4.4 for details).
- Geotextile around the perimeter of the drainage trench. The geotextile is needed to prevent loss of fines from the surrounding soil through the collector drain and to prevent clogging of the drainage pipes. Note that the drainage trench is open to the base being drained for both dense-graded aggregate and permeable base systems to allow unimpeded flow of water into the drainage trench.
- Permeable backfill.
- Impervious cap. The impervious cap is a very important design detail to prevent infiltration of surface runoff into the collector drain. If an asphalt shoulder is provided, there is no need for a separate cap. If the pavement will have a turf area at the pavement edge rather than a paved shoulder, the impervious cap must consist of a minimum 3 in (76 mm) of cohesive backfill.

The use of prefabricated geocomposite edgedrains is not recommended for base course drainage because they cannot be maintained.

(2) Permeable Base System. A permeable base system consists of the following components (see section 4.4 for design details):

- A permeable base layer for rapid removal of infiltrated water out of the pavement structure.
- A separator layer to prevent infiltration of subgrade fines into the permeable base.
- Collector drains to direct water draining out of the pavement structure to drainage outlets.
- Regularly spaced outlets.

b. Subgrade Drains. A subgrade drain may consist of an open ditch or subsurface collector drains similar to those for base course drainage. In general, it should be possible to design base course drains to handle subgrade drainage. Where separate subgrade drains are needed, the designs shown in figure 16 may be used. For both designs shown in figure 16, the permeability of the aggregate filter backfill must be greater than that of the subgrade being drained.

c. Interceptor Drains. Interceptor drains may be combined with base course drains. Where separate interceptor drains are needed, the designs shown in figure 16 may be used.

d. Combination of Surface and Subsurface Drainage. The surface runoff should never be allowed to drain into the collector drains for subsurface drainage. Provide entirely separate system of collector drains for surface runoff and subsurface water. It is, however, permissible to outlet subsurface water into storm drain inlet structures when the collector drains for subsurface drainage cannot be easily outlet into open drainage ditches. See section 4.4 for design details.

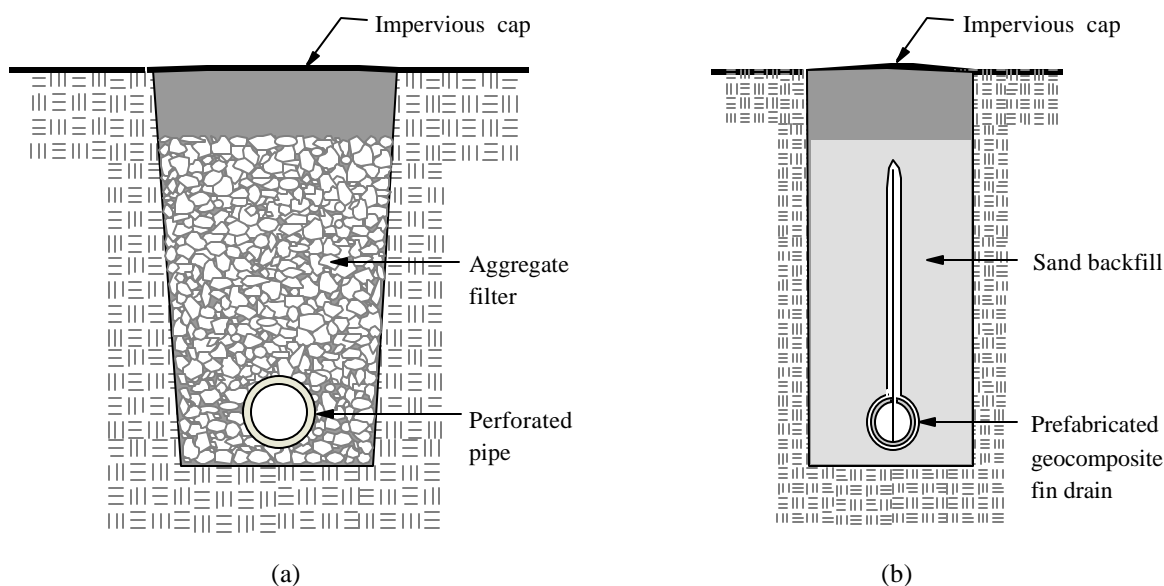


Figure 16. Design alternatives for subgrade and interceptor drains.

4. DESIGN DETAILS.

a. Collector Drains for Base Course Drainage. The recommended design details for the collector drains are shown in figures 14 and 15.

(1) Location of Collector Drains. Place the drains only at runway and taxiway edges, except under unusual circumstances where this is not possible. Large paved areas, such as parking aprons, will generally require intermediate drains. The design details for interior drains are shown in figure 17.

(2) Trench Dimensions. See figures 15 and 16 for trench details. The requirements are as follows:

- A minimum clearance of 6 in (152 mm) on either side of the drainage pipe.
- Adequate depth to place the center of the drainage pipe a minimum of 12 in (305 mm) below the bottom of the base or separator layer, with room for 2 in (51 mm) of bedding beneath the drainage pipes. Interior drains (figure 17) in flexible pavements may require a deeper trench to satisfy the cover requirements. In seasonal frost areas, the drainage pipes must be placed below the frost depth; however, drainage pipes need not be placed deeper than 48 in (1.2 m) below the bottom of the base layer.

(3) Slopes. The recommended minimum slope for collector drains is 0.15 percent (0.0015 ft/ft [m/m]). If this minimum slope cannot be achieved, provide outlets at 250-ft (75-m) intervals.

(4) Geotextile Placement. Line the drainage trench with geotextile as shown in figures 14, 15, or 17 to prevent contamination of the collector drains by fines from surrounding subgrade. Use a nonwoven needle punched fabric meeting the criteria given in section 3.5.b.2.

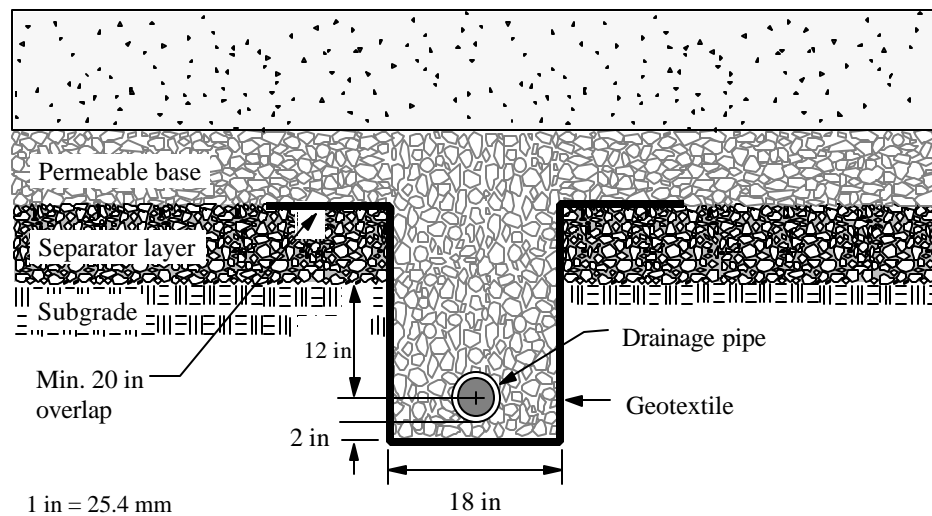


Figure 17. Typical design detail for interior collector drains.

(5) Drainage Pipe. Use either corrugated polyethylene (CPE) or smooth rigid polyvinyl chloride (PVC) pipes with perforations. Use 6-in minimum diameter pipe. In general, 6-in (152-mm) diameter pipe will provide adequate hydraulic capacity and satisfy maintenance requirements. The applicable specifications for drainage pipes are as follows:

- Corrugated (CPE) pipes — AASHTO M252.
- Smooth rigid PVC pipes — AASHTO M278 Class PC50.
- Corrugated pipes with smooth interior — ASTM F 949 for PVC and AASHTO M252 for CPE pipes.

If an asphalt-treated permeable material will be used to backfill the drainage trench, the drainage pipe must be capable of withstanding high temperatures. Use PVC electric conduit EPC 40 or EPC 80 that meets National Electrical Manufacturers Association (NEMA) Specification TC-2.

(6) Pipe Cover. Pipe cover is a concern for the drains located in trafficked areas. In general, the collector drains placed along the pavement edges are located beyond the traffic area and only the interior drains (figure 17) will be subjected to live loads. For loads up to 100,000-lb (45-kN) dual-wheel, the detail shown in figure 17 provides adequate cover for pipe drains under rigid pavements. For flexible pavements, additional cover may be required if the total pavement thickness over the drainage trench (excluding the trench backfill) is less than 2 ft (0.6 m). Cover requirements for different design wheel loads are indicated in TM 58203/AFM 885, Chapter 3.

(7) Backfill Material. The trench backfill material must be stable and at least as permeable as the base being drained. In general, the same material used in the permeable base should be used.

b. Dense-Graded Base System

(1) Dense-Graded Base. A dense-graded aggregate base with a moderately high permeability may be used as a drainage layer. For typical design conditions, a base permeability of at least 20 ft/day (6.1 m/day) for runways and 10 ft/day (3.0 m/day) for taxiways is required to satisfy the time-to-drain requirement. An aggregate base used as the drainage layer must contain no more than 15 percent of fines passing the No. 200 sieve (0.075 mm) to prevent clogging of the edgedrains or loss of fines through the edgedrains. In general, an aggregate material that satisfies the permeability requirement will satisfy the fines-content requirement. To ensure good stability, use only 100 percent crushed stone.

(2) Protection of the Drainage Layer. A dense-graded aggregate that meets the permeability requirements of a drainage layer will generally contain fewer fines (material passing No. 200 sieve [0.075 mm]) than a typical dense-graded base. To prevent contamination and loss of permeability, the drainage layer must be adequately protected from the underlying materials. If the filter criteria (equations 1 and 2) are not satisfied, a geotextile separator layer should be used to protect the drainage layer. The use of a geotextile separator layer is also recommended for projects in wet or freeze climate, if either of the following conditions exist:

- Silty or clayey subgrade (A-4 or A-6).
- Subgrade CBR < 4.

c. Permeable Base System

(1) Permeable Base. In general, a gradation that has permeability of about 1,000 ft/day (300 m/day) will provide adequate drainage capacity and stability. To ensure good stability, use only 100 percent crushed stone, and the aggregate should be graded to provide coefficient of uniformity (equation 5) greater than 4.0. Example permeable base gradations are given in table 7. Only a stabilized permeable base should be used on airfield pavements.

- Asphalt-treated permeable base — A minimum AC content of 2.5 percent by weight is recommended. Use a harder grade of asphalt cement (e.g., AC 40 or AR 8000).
- Cement-treated permeable base — Application rate of 2 to 3 bags/yd³ (112 to 167 kg/m³) is recommended.

Table 7. Example permeable base gradations.

Sieve Size		Rapid Draining Material (RDM)	New Jersey
1 in	25 mm	70 – 100	95 – 100
¾ in	19 mm	55 – 100	
½ in	12.5 mm	40 – 80	60 – 80
3/8 in	9.5 mm	30 – 65	
No. 4	4.75 mm	10 – 50	40 – 55
No. 8	2.36 mm	0 – 25	5 – 25
No. 16	1.18 mm	0 – 5	0 – 8
No. 50	300 µm		0 – 5
CU		> 3.5	> 4
Coefficient of Permeability, k		1,000 to 5,000 ft/day 300 to 1,500 m/day	1,000 ft/day 300 m/day

Use 6-in (152-mm) thick asphalt- or cement-treated permeable base for airfield pavement applications. The permeable base should be placed directly below the pavement slabs in rigid pavements and immediately below the last stabilized layer in flexible pavements. An unbound aggregate layer may be placed above the permeable base layer in flexible pavements if the aggregate material satisfies the following requirements:

- Contains less than 8 percent of fines passing the No. 200 (0.075 mm) sieve.
- Satisfies the filter criteria specified in section 3.5.b.
- Has a coefficient of permeability greater than 2 ft/day (0.6 m/day).

(2) Separator Layer. The separator layer is an essential component of a permeable base system. Provide a minimum 6-in thick unbound aggregate separator layer. The requirements for the aggregate separator layer are as follows:

- Satisfies the filter criteria specified in section 3.5.b.
- Contains less than 12 percent of fines passing the No. 200 sieve (0.075 mm).
- Has a coefficient of uniformity of at least 20 (preferably greater than 40).

In general, typical dense-graded aggregate base material will satisfy these requirements. Table 8 provides an example gradation that satisfies these requirements. Table 9 lists geotextiles that may be used as a separator layer. A geotextile may be placed between the aggregate separator layer and the permeable base to provide the most positive protection of the permeable base, but the use of the geotextile by itself as a separator layer is not recommended. The use of both geotextile and aggregate separator layers may be appropriate if the subgrade at the project site is very soft (e.g., CBR < 4). A geotextile separator layer must satisfy the filter criteria specified in section 3.5.b.

Table 8. Example aggregate separator layer gradation.

Sieve Size		Aggregate Separator Layer Material
1 in	25 mm	100
3/4 in	19 mm	95 – 100
No. 4	4.75 mm	50 – 80
No. 40	425 μ m	20 – 35
No. 200	75 μ m	5 – 12
<i>CU</i>		40

d. Subgrade and Interceptor Drains. The subgrade and interceptor drains can be combined with the base course drains. If separate drains are needed, the designs shown in figure 16 can be used. In general, the pipe drain is preferred because of maintenance considerations.

(1) Pipe Drains. The trench detail for the pipe drain is the same as that for the base course drains. The backfill material for the pipe drain must have permeability greater than the subgrade being drained and satisfy the filter criteria specified in section 3.5.b. In addition, the backfill material must satisfy the following criteria to prevent loss of fines through the drainage pipes:

- Slotted pipes: D_{85} of backfill $>$ 1.2 slot width.
- Pipes with circular holes: D_{85} of backfill $>$ 1.0 hole diameter.

These requirements need not be checked for permeable backfill. If permeable backfill is used, the drainage trench must be wrapped with geotextile. In general, because of low permeability requirements, a permeable backfill will not be required for subgrade or interceptor drains.

(2) Geocomposite Drains. The trench detail for prefabricated geocomposite collector drains is similar to that for pipe drains, except the recommended trench width is 8 to 12 in (203 to 305 mm). Excessive compaction can crush geocomposite drains. Backfill the drainage trench with coarse sand that satisfies the filter criteria (section 3.5.b) and compact by flushing with water.

e. Outlet Design. Dual outlets are recommended for maintenance considerations, as shown in figure 18. The dual outlet system allows sections of collector drains to be flushed out to clear any debris or material blocking the free flow of water. The recommended design details for drainage outlets are as follows:

- Provide dual outlet with large-radius bends, as shown in figure 19.
- Use rigid-walled, non-perforated pipes. For pipe drains, use the same diameter pipe as the collector drains. For prefabricated geocomposite drains, 4- to 6-in (102- to 152-mm) diameter pipe should provide adequate hydraulic capacity. The flow capacity of the outlets must be greater than that of the collector drains. In general, because of the greater slope provided for outlet pipes, the hydraulic capacity is not a problem.
- A minimum 3 percent slope is recommended for outlet pipes.

- The discharge end of the outlet pipe should be placed at least 6 in (152 mm) above the 10-year design flow in the drainage ditch (figure 20). The same requirement applies even if the outlet is discharging into storm drain inlets.
- Provide headwalls as shown in figure 21. Headwalls and clear marking of outlets is very important for proper maintenance.

f. Manholes and Observation Basins . Where collector drains do not outlet into an open drainage ditch, provide manholes, observation basins, and risers for access to the drainage system for inspection and maintenance. See NAVFAC DM-5.03 for number, location, spacing, and design.

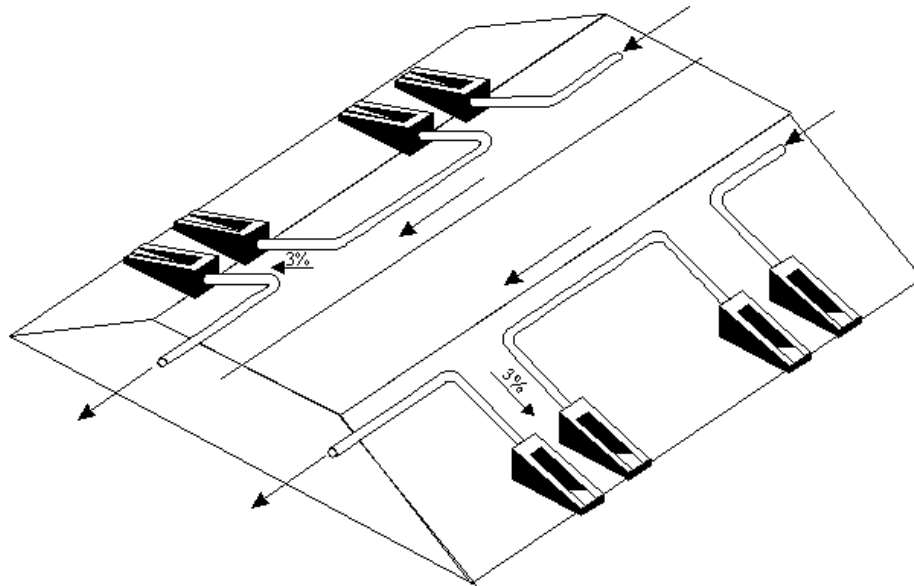


Figure 18. Schematic of dual outlet system layout (Baumgardner 1998).

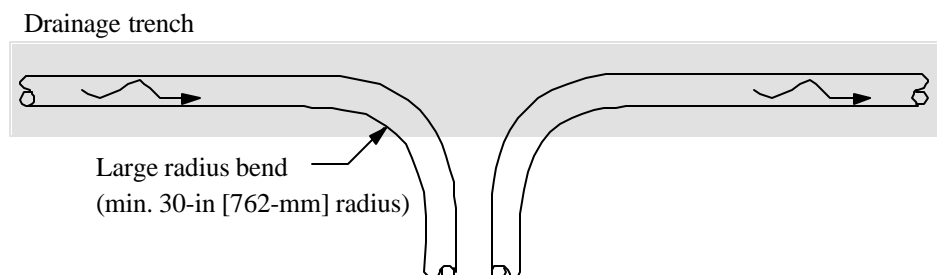


Figure 19. Illustration of large-radius bends recommended for drainage outlet.

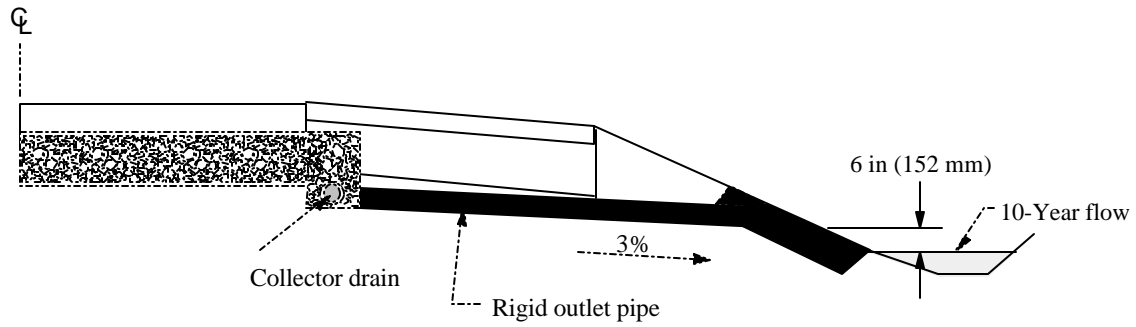


Figure 20. Recommended outlet design detail.

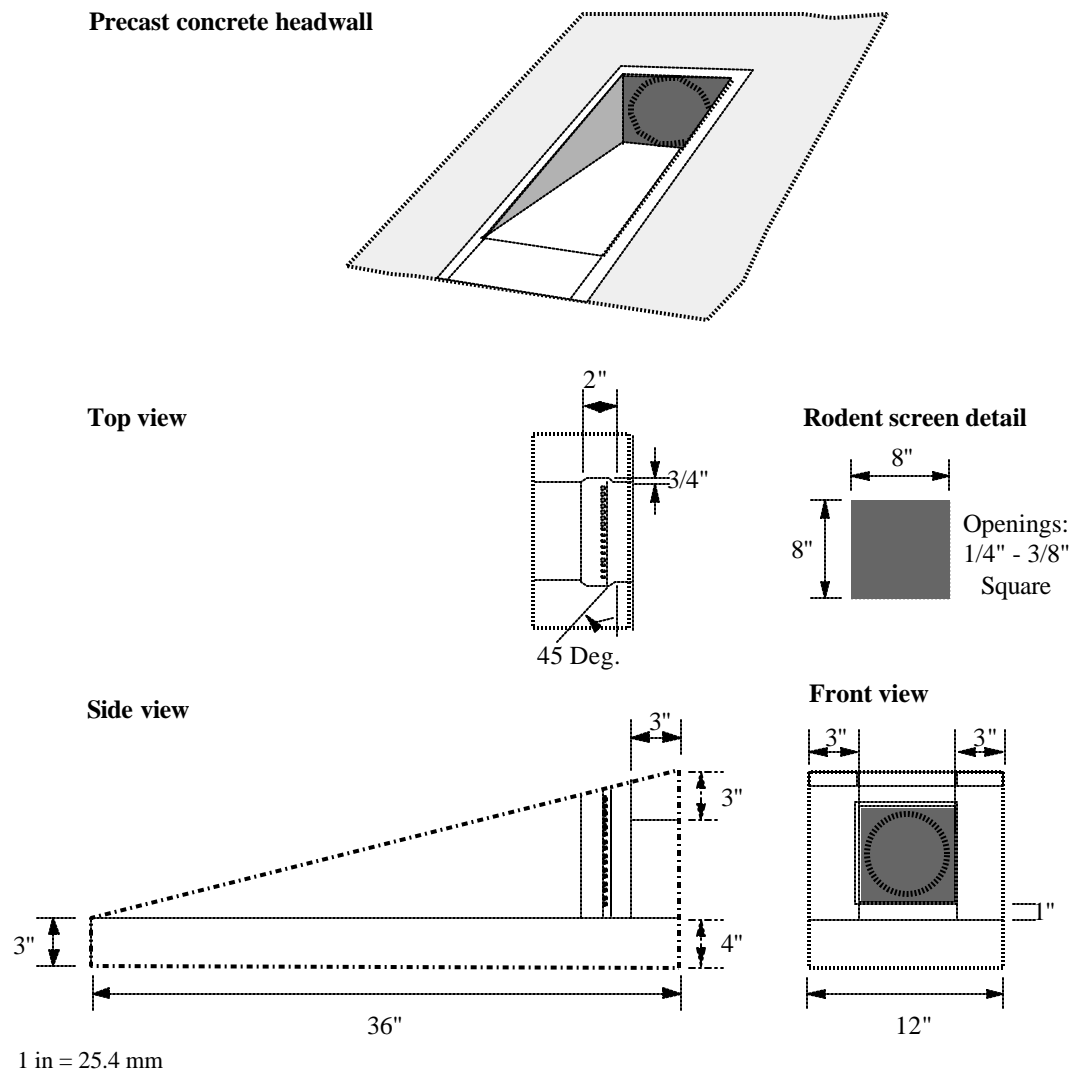


Figure 21. Recommended headwall design for drainage outlets.

SECTION 5. CONSTRUCTION OF SUBSURFACE DRAINAGE SYSTEMS

1. GENERAL. The construction of a drainage system includes handling and placement of a variety of materials, including permeable drainage layers, dense-graded separator layers, geotextiles, and plastic or metallic pipes. Drainage systems can be constructed without undue difficulties if a few precautionary measures are taken. The key to successful construction lies in training of the personnel involved to ensure that special requirements of drainage systems are properly addressed.

2. CONSIDERATIONS FOR SUBGRADE SOIL TREATMENTS. A stable foundation is essential to a permeable base system for both construction and long-term performance considerations. Soft subgrades do not provide adequate support for construction traffic and for the compaction of the overlying layers. Moreover, a poor subgrade promotes pumping of the subgrade fines into the permeable base, as well as intermixing at the permeable base–separator layer and separator layer–subgrade interfaces. The intermixing results in contamination of the permeable base and significant loss of permeability. A minimum California Bearing Ratio (CBR) of 4 is recommended for pavements provided with a permeable base. If the CBR requirement cannot be met, placement of a thick granular fill or subgrade improvement through either mechanical or chemical (lime or cement) stabilization is highly recommended.

3. PLACEMENT OF PERMEABLE BASE. Permeable base materials are susceptible to segregation due to their open-graded nature. Therefore, special care should be taken to avoid this problem while stockpiling or placing these materials. Hauling on permeable bases should be kept to a minimum, and care should be taken to avoid excessive rutting and shoving of materials under construction traffic. When a permeable base is being placed over a geotextile separation layer, sharp turns of the construction equipment should be avoided to prevent wear and tear of the geotextile. After placement, the drainage layer should be protected to prevent contamination with fines or other foreign materials. Any contaminated area should be completely removed and replaced with new material. Minimal construction traffic should be allowed on the completed permeable base. Only tracked pavers should be used to pave over the permeable base. The following are additional considerations for placement and compaction of permeable bases:

a. Asphalt-Treated Permeable Base.

- The aggregates should be preheated to between 275 and 325 °F (135 and 163 °C).
- The temperature-viscosity relationship of the asphalt binder should be used to determine the mixing temperatures. For AC-40 (or equivalent performance-grade asphalt), the recommended mixing temperatures are between 230 and 280 °F (110 and 138 °C).
- The compaction process should begin and end when the asphalt temperature is between 150 and 100 °F (66 and 38 °C) for AC-40 or equivalent binder.
- Conventional asphalt paving machines can be used to place the permeable base materials.
- One to three passes of a 5- to 10-ton (4.5 to 9.1 Mg) steel-wheeled static roller are adequate to seat and compact the aggregate.

b. Cement-Treated Permeable Base.

- The cement-treated permeable base can be placed using a spreading machine or a subgrade planer. A paver should follow the spreader.
- Vibratory plates and screeds on the paving machine can be used for compacting.
- Polyethylene sheeting, water mist curing, and chemical curing have all been used to cure the cement-treated permeable bases. A test strip should be constructed to determine the curing method that works best for the given situation.

4. CONSTRUCTION OF COLLECTOR DRAINS.

a. Edgedrain Location. The location of the edgedrain relative to the pavement is a function of the construction sequence. In pre-pave installations, the edgedrain trench should be located far enough away from the pavement edge so that the paver tracks do not run directly over the trench. In post-pave installations, the edgedrains are installed after the pavement is constructed. In this case, the edgedrains should be placed far enough away from the pavement edge to prevent loss of support underneath the pavement. The pre-pave or post-pave decision may be left with the contractor.

b. Trenching. The trench should be cut at a constant depth so that the bottom of the trench follows the pavement grade. A 2-in (51-mm) layer of bedding material is recommended beneath the drainage pipe. To obtain proper line and grade, the bottom of the trench should be grooved to cradle the lower one-third of the pipe. The bedding groove helps in holding the pipe in place during installation. The shape of the groove should closely match the shape of the pipe.

c. Geotextile Lining. The trench should be lined with a geotextile to prevent the migration of fines from the surrounding soil. The lining should be such that the portion of the trench adjacent to the permeable base should be open in order to allow free access for the water percolating through the base.

d. Pipe Placement. When placing CPE (corrugated) pipes, care should be taken to prevent overstretching. A maximum tolerance of 5 percent is allowed for overstretching.

e. Trench Backfill. Prior to backfilling the trench, the connections between the pipes and the outlets must be secured. The material used for trench backfill should be stable and at least as permeable as the permeable base material. The backfill material should be gently placed into the trench using chutes in order to avoid damaging the edgedrain pipe. The pipes should not be compacted until a cover of 6 in (152 mm) is established over the pipes. A high energy Vermeer vibratory wheel can be used to compact the trench backfill in two lifts. A minimum target density of 95 percent standard Proctor (AASHTO T 99) is recommended for the trench backfill.

5. CONSTRUCTION QUALITY MONITORING. Proper construction of the subsurface drainage system involves continual monitoring of all its components during the construction phase. This is especially true for the collector drains and drainage outlets. Several studies have documented that a significant percentage of edgedrains and outlets are rendered nonfunctional by the time construction is complete.

a. Visual Inspection. Visual inspection during construction is extremely important to achieve properly functioning drainage system. The following items warrant special attention:

- Drainage trench dimensions and slope — Ensure that collector drain trenches are excavated to proper depth and slope.
- Geotextile placement — Ensure that geotextiles are placed as specified and kept clear of contaminants (e.g., fines from surrounding soil). To prevent contamination, the geotextile should be placed just prior to installing drainage pipes. Ensure that the collector drain is open to the base being drained as shown in figures 14, 15, and 17.
- Pipe installation — Ensure that the drainage pipes are installed with proper slope and that the pipes are properly connected. Sagging and lateral undulations can be a problem for corrugated (CPE) pipes. Check all connections (between sections of collector drain pipes, collector drain to outlet pipe connection, and connection between outlet pipes and headwalls).

b. Acceptance. Video inspection of the completed drainage systems is highly recommended as an acceptance tool. A detailed list of equipment used in an FHWA study (Daleiden 1998) is given in table 10. A video inspection system typically consists of a camera head, long flexible probe mounted on a frame for inserting the camera head into the pipe, and a data acquisition unit fitted with a video screen and a video recorder. This system can be used to detect and correct any construction problems before a project is accepted. The construction-related problems that are easily detected using the video equipment include crushed or ruptured drainage pipes and improper connections between drainage pipes, as well as the connection between the outlet pipe and headwall.

Table 10. Equipment description for FHWA video inspection study (Daleiden 1998).

Camera: The camera is a Pearpoint flexiprobe high-resolution, high-sensitivity, waterproof color video camera engineered to inspect pipes 3 to 6 in (76 to 152 mm) in diameter. The flexiprobe lighthead and camera has a physical size of 2.8 in (71 mm) and is capable of negotiating 4 in x 4 in (102 mm x 102 mm) plastic tees. The lighthead incorporates six high-intensity lights. This lighting provides the ability to obtain a “true” color picture of the entire surface periphery of a pipe. The camera includes a detachable hard plastic ball that centers the camera during pipe inspections.
Camera Control Unit: The portable color control unit includes a built-in 8-in (203-mm) color monitor and controls including remote iris, focus, video input/output, audio in with built-in speaker, and light level intensity control. Two VCR input/output jacks are provided for video recording as well as tape playback verification through the built-in monitor.
Metal Coiler and Push Rod With Counter: The portable coiler contains 150 m of integrated semi-rigid push rod, gold and rhodium slip rings, electro-mechanical cable counter, and electrical cable. The integrated push rod/electrical cable consists of a special epoxy glass reinforced rod with polypropylene sheathing material, which will allow for lengthy inspections due to the semi-rigid nature of this system.
Video Cassette Recorder: The video cassette recorder is a high-quality four-head industrial grade VHS recorder with audio dubbing, still frame, and slow speed capabilities.
Generator : A compact portable generator capable of providing 650 watts at 115 V to power the inspection equipment.
Molded Transportation Case: A molded transportation case, specifically built for air transportation, encases the control unit, camera, and videocassette recorder.
Color Video Printer: A video printer is incorporated into the system to allow the technician to obtain color prints of pipe anomalies or areas of interest.

SECTION 6. MAINTENANCE OF SUBSURFACE DRAINAGE SYSTEMS

1. MONITORING PROGRAM. Commitment to maintenance is as important as providing subsurface drainage systems. In fact, an improperly maintained drainage system can cause more damage to the pavement structure than if no drainage were provided at all. Poor maintenance leads to clogged or silted outlets and edgedrain pipes, missing rodent screens, excessive growth of vegetation blocking outlet pipes and openings on daylighted bases, and growth of vegetation in side ditches. These problems can potentially cause backing up of water within the pavement system, thereby defeating the purpose of providing the drainage system. Therefore, inspections and maintenance of subsurface drainage systems should be made an integral part of the policy of any agency installing these systems. The inspection process comprises of two parts: (a) visual inspection and (b) video inspection.

a. Visual Inspection. The visual inspection process includes the following items:

- Evaluation of external drainage-related features, including measurement of ditch depths and checking for crushed outlets, excessive vegetative growth, clogged and debris-filled daylighted openings, condition of headwalls, presence of erosion, and missing rodent screens. This operation should be performed at least once a year.
- Pavement condition evaluation to check for moisture-related pavement distresses such as pumping, faulting, and D-cracking in PCC pavements and fatigue cracking and AC stripping in AC pavements. This operation could be either a full-scale PCI survey or a brief overview survey, depending on agency needs. The recommended frequency for this activity is once every 2 years.

b. Video Inspection. Video inspections play a vital role in monitoring in-service drainage systems. The video inspection process can be used to check for clogged drains due to silting and intrusion of surrounding soil, as well as any problems with the drainage system, such as ruptured pipes and broken connections. Video inspections should be carried out on an “as-needed” basis whenever there is evidence of drainage-related problems. The equipment for video inspection is described in section 5.5.b.

2. MAINTENANCE GUIDELINES

a. Collector Drains and Outlets. The collector drains and outlets should be flushed periodically with high-pressure water jets to loosen and remove any sediment that has built up within the system. The key to this operation is having the appropriate outlet details that facilitate the process, such as the dual headwall system suggested in section 4. The area around the outlet pipes should be kept mowed to prevent any buildup of water. Missing rodent screens and outlet markers, damaged pipes and headwalls need to be either repaired or replaced.

b. Daylighted Systems. Routine removal of roadside debris and vegetation clogging the daylighted openings of a permeable or dense-graded base is very important for maintaining the functionality of these systems.

c. Drainage Ditches. The drainage ditches should be kept mowed to prevent excessive vegetative growth. Debris and silt deposited at the bottom of the ditch should be cleaned periodically to maintain the ditch line and to prevent water from backing up into the pavement system.

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APPENDIX A. GLOSSARY

Apparent Opening Size (AOS) — A measure of the opening size of a geotextile. AOS is the sieve number corresponding to the sieve size at which 95 percent of the single-size glass beads pass the geotextile (O_{95}) when tested in accordance with ASTM D 4751, *Determining Apparent Opening Size (AOS) of a Geotextile*.

Average Daily Temperature — The average of the maximum and minimum temperatures for one day, or the average of several temperature readings taken at equal time intervals (typically on an hourly basis) during one day.

Coefficient of Permeability (k) — A measure of the rate at which water passes through a unit area of material in a given amount of time under a unit hydraulic gradient.

Degree-Days — The degree-days for any one day is the difference between the average daily air temperature and 32 °F. The degree days are negative when the average daily temperature is below 32 °F (freezing degree-days) and positive when it is above 32 °F (thawing degree-days). Figure 5 shows curves obtained by plotting cumulative degree-days against time.

Design Freezing Index — The average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the index for the latest 10-year period may be used. Design freezing index is illustrated in figure 5.

Drainage Layer — A layer in the pavement structure that is specifically designed to allow rapid horizontal drainage of water from the pavement structure. The layer is also considered to be a structural component of the pavement and may serve as a part of the base.

Effective Porosity — The effective porosity is the ratio of the volume of voids that will drain under the influence of gravity to the total volume of a unit of aggregate. The difference between the porosity and the effective porosity is the amount of water that will be held by the aggregate.

Freezing Index — The number of degree-days between the highest and lowest points on a cumulative degree-days versus time curve for one freezing season. Freezing Index is a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 4.5 ft (1.35 m) above the ground is commonly designated as the air freezing index, while that determined for temperatures immediately below the surface is known as the surface freezing index.

Frost — As it relates to pavements, frost is the condition of free water freezing within the pavement structure or in the subgrade. The action of frost includes expansion or heaving, as well as the loss of support during the melt period. The frost action may result in the formation of ice crystals in any frost-susceptible material within or below the pavement structure to which freezing temperatures penetrate.

Geotextile — A permeable textile used in geotechnical projects. In this manual, geotextile refers to a nonwoven needle punch fabric that meets the requirements of the apparent opening size, grab strength, and puncture strength specified for the particular application.

Geocomposite Edgedrain — A prefabricated product using geotextiles, geogrids, geonets, or geomembranes in laminated or composite form, which can be used as an edgedrain in place of trench-pipe construction.

Mean Daily Temperature — The average of the average daily temperatures for a given day for several years.

Mean Freezing Index — The freezing index determined based on mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 years, the preferred being 30 years. The latest available data should be used. Mean freezing index is illustrated in figure 5.

Pavement Structure — Pavement structure is the combination of subbase, base, and surface layers constructed on a subgrade.

Permeable Base — An open-graded granular material with most of the fines removed (e.g., less than 10 percent passing the No. 8 sieve) to provide high permeability (1,000 ft/day or more) for use in a drainage layer.

Porosity — The amount of voids in a material, expressed as the ratio of the volume of voids to the total volume.

Pumping — Ejection of free water in the pavement layers under the action of moving wheel loads. The water being ejected carries out with it any erodible fines in the pavement layers or from the top of the subgrade, creating voids and loss of support. Under saturated conditions, the combination of the presence of excess free water and large deflections caused by moving wheel loads can also cause migration of subgrade fines into the base or subbase layers.

Separator Layer — A layer provided directly beneath the drainage layer to prevent fines from infiltrating or pumping into the drainage layer and to provide a stable foundation for the drainage layer.

Stabilization — Use of either portland cement or asphalt to increase stability of the base material to withstand construction traffic or to provide additional structural support for the surface layer. Subgrade soil may also be stabilized with either lime or portland cement to provide a good working platform for construction purposes, as well as to improve foundation support for the pavement structure.

Subsurface Drainage — Collection and removal of water from a pavement structure or subgrade. Subsurface drainage systems are categorized into two functional categories: one for draining surface infiltration water, and the other for controlling groundwater.